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Original Article

An Introspection into the Evolution of Microstrip Patch Antenna Design Techniques for Enhanced Wireless Applications

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Abstract *- An antenna plays a pivotal role in a wireless application system. A Microstrip Patch Antenna is widely used in advanced wireless communication and is characterized by high gain and narrow bandwidth. As a result of the developments in wireless networks and integrated circuit technology, patch antennas are being widely implemented as printed antenna for wireless communication, satellite communication, microwave communication and cell phones. It has gained much attention over the past years due to its compact structure, low weight, low profile, low cost and capability to reconfigure on different frequency bands. Furthermore, a hybrid combination of a slot and patch antenna can enhance the overall performance parameters. This paper examines the evolution of various designing, simulation and fabrication techniques adopted for designing microstrip patch antenna. This research delves into various microstrip patch antenna design aspects, including substrate material selection, geometrical configuration, feed techniques, and bandwidth enhancement methods. A currently designed antenna has been investigated, rendering a comparative analysis of enhanced performance parameters such as bandwidth dimensions of the patch, return loss, directivity and efficiency for various patch antenna designs.*

Keywords *- Bandwidth, Efficiency, Microstrip Patch Antenna, Reconfigurable antennas, Defected ground structure.*

1. Introduction

In recent years, there has been phenomenal progress in Wireless communication systems. This has created a thrust for design enhancements in the conventional antenna structures. In line with this, a Microstrip Patch Antenna (MPA) offers Miniaturized size, wider bandwidth, enhanced radiation, improvised fabrication and integration capabilities.

A Microstrip Antenna (MSA) is a compact antenna comprising two metallic planes separated by a dielectric Substrate. The bottom layer constitutes the ground plane, whereas the top layer is a radiating patch. These two planes are isolated with a low loss dielectric medium known as substrate. As the technique of manufacturing a printed circuit board and Microstrip Antenna is identical, a Microstrip Antenna is also known as a "printed antenna" [1]. The conducting slot radiates due to the fringing fields developed at the corners of the upper metallic layer and the reference plane. An inherent advantage of using a Microstrip Patch Antenna (MPA) is its simple feeding mechanism and the ease of interfacing with other ICs. Additionally, MPA can be used in arrays and with other microstrip circuit devices. The patch fabricated in the antenna can be rectangular, square, circular, dipole, triangular, elliptical, disc sector, circular ring, ring sector, but the most popularly used shapes are circle and rectangle. Furthermore, the dielectric resonator antennas loaded with these features are being upgraded continuously to meet these diverse requirements and have been under investigation for the past two decades [2].

Two crucial parameters that affect the antenna's performance are its size and shape. Furthermore, the dimensions of the substrate are essential [3] from the designing perspective. A significant limitation of an antenna is narrow bandwidth and gain adjustment. From the application perspective, bandwidth is a crucial parameter. and needs to be enhanced for wideband performance [4]. Figure 1 represents a variety of shapes assumed by a rectangular 1(a) the square 1(b) the rectangle, 1(c) the circle,1(d) the triangle, 1(e) the donut, and 1(f) the dipole.

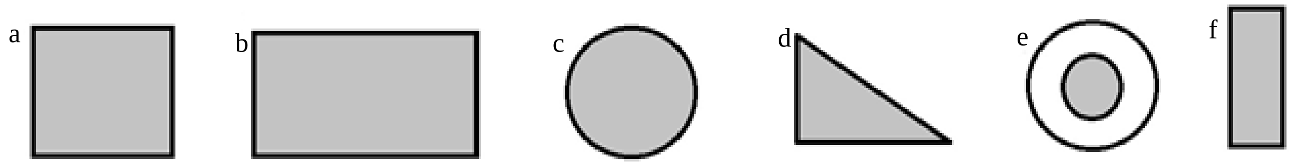

Fig. 1 Discrete shapes employed for designing of Microstrip Patch Antenna: 1(a) The square, 1(b) The rectangle, 1(c) The circle, 1(d) The triangle, 1(e) The donut, and 1(f) The dipole.

2. Literature Review

This section provides the chronological development of patch antenna as various designers propose.

Sohel Rana et al. 2023 proposed an MPA operating at a design frequency of 2.45 GHz. This work analyses the performance of two materials in antenna design, FR4 & Roggers RT duroid. After a comparative parametric analysis of the antenna materials, it is revealed that the performance of the antenna employing Roggers RT duroid rendered better results in terms of superior gain of 2.59 dB, return loss of -12.54 dB, directivity gain of 8.58 dBi, VSWR of 1.61 and efficiency close to 94 % approximately concerning its counterpart FR4. It exhibits excellent radiation and can work over a wide frequency band [2].

Firoz Ahmed et al. 2023 have proposed a compact rectangular patch with enhanced bandwidth and efficiency, employing a hybrid technique, thereby increasing its suitability for UWB applications. This designed antenna uses a defected ground structure as the initial stage. The proposed design considers various crucial antenna design parameters such as oscillation frequency, patch width and length, dielectric constant, and ground plane dimensions. The proposed method yields an improved efficiency of 95.77 % and a bandwidth of 19.7 GHz. This design has rendered a bandwidth and efficiency enhancement of nearly 17 GHz and 3.5 % concerning a basic antenna with DGS. This design becomes a better candidate for Wireless applications [3].

Mouaaz Nahas 2022 has suggested a dual-band patch antenna utilizing a LI slot as a suitable candidate for 5G communications. This design employs various permutations & combinations of multiple LI slots. The objective was to maintain the antennas at resonance values of 28 GHz and 26 GHz, respectively. Four sets of designs have been suggested and compared with each other. It is observed that the four designs render a performance far superior to the identical designs proposed by other designers. It was investigated that the slotted antenna designs employing various configurations were suitable for 5G communication equipment, in which case simple design and small size are the essential constraints for evaluation [4].

Mohammad Sarwar Hossain Mollah et al. 2021 have proposed a Patch antenna using graphene as the base material. The primary goal of the work is obtaining better performance. The designed antenna at 2.45 GHz renders a maximum return loss of -23.67 dB, directivity of 7.30 dBi and a gain of 6.80 dB. The paper presents a comparative performance analysis of the designs employing different materials. It is established that graphene drastically improves the scattering parameter compared to a primary antenna utilizing a DGS as a reference plane.

Feibiao Dong et al. 2017 proposed and investigated an antenna using a wideband Dielectric resonator with a high gain and low cross-polarization. The emphasis is laid on the improvement of bandwidth and gain. A return loss of -10 dB with an efficiency of 25.6%.This further yields an average increase of 7.54 dBi. Due to the simplicity of the antenna design, it can be utilized to form an antenna array [1].

Rahul Dev Mishra et al. 2016 proposed MPA using several microstrip elements to form an array. The primary objective is to improve the overall gain and bandwidth. The antenna is designed at a frequency of 2.48 GHz using FR4 at a dielectric constant of 4.3. In this design, two rectangular patches of identical size are combined to improve the return loss and reflection coefficient, besides improvement in bandwidth and gain as iterated earlier [7].

Huda A. Majid et al. 2014 suggested a frequency reconfigurable Microstrip Patch-slot Antenna having a directional radiation pattern. The proposed antenna can reconfigure up to six frequencies from 1.7 GHz to 3.5 GHz. A reflector has been incorporated into this design, enhancing the antenna's directivity. The frequency switching is achieved by employing switches in the antenna slot [18].

Ahmed Khidre et al. 2013 present a reconfigurable wideband antenna with circular polarization and E shaped patch. The antenna is fabricated on a plane sheet of RT-droid 5880 with a dielectric substrate with a permittivity of 2.2. A narrow slit is etched on the E-shaped pattern. The final design exhibits a bandwidth improvement of 7% with a gain of 7.5 dBi. The fabricated antenna structure covers the WLAN IEEE 802.11 b/g to be used in a band of frequencies in stationary terminals of wireless applications [13].

Hongjiang. Z et al. 2012 suggested a high gain patch antenna to form a wired Yagi-Uda array operating in the frequency band of 5.45 to 5.75 GHz. In this design, wired patch antennas replace the Yagi-uda element [15].

Abolfazl, A. et al. 2011 present a Microstrip Antenna using fractal terminology that renders a broad band of operation. It has been established that the prototype can operate over a frequency band of 10-50 GHz and a 40 GHz bandwidth.

3. Design Methodology

An insight into the basic design procedure adopted for designing a Rectangular Microstrip Patch Antenna (RMPA) and feeding techniques employed, emphasising improvement of bandwidth, gain, return loss, directive gain and other scattering parameters, is introduced.

3.1. Rectangular MPA Design Using HFSS

Figure 2 represents the basic topology of a MPA. This design utilizes two basic materials, FR4 and glass, as dielectric materials. The antenna's bandwidth can be modified by varying the dimensions & shape. This technique is known as dimensional optimization. The bandwidth primarily depends upon the dielectric medium's thickness and the designed patch's width [5]. Table 1 gives the parametric details of the incorporated dielectric material, the feeding method used, and the type of simulation software employed in the design.

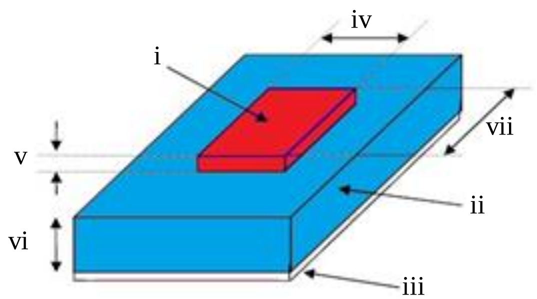

Fig. 2 A layout of Rectangular Microstrip Patch Antenna with (i) Patch, (ii) Dielectric substrate, (iii) Ground plane, (iv) Length (l) of the patch, (v) Thickness, (t) of the patch, (vi) Height of dielectric medium (h), (vii) Width, and (w) of the patch.

Table 1. Parametric details of the RMPA design using various dielectric materials

S. No.	Details	Table Header
Dielectric Material Used	Glass	FR-4
Width (Mm)	20.8	22.6
Length (Mm)	14.77	16.6
Resonant Frequency	4.1 GHz	4.06 GHz
Return Loss	-6.4 dB	-10.4dB
Gain	6.6dB	6.92 dB
Dielectric Constant (Ɛ)	5.5	4.4
Reflection Coefficient (S_{11})	-10	-10.4

The parametric calculations make use of the following equations. Equation 1 gives the Width (W) of the patch in MPA.

$$\mathrm{W} = \frac{C\sqrt{2}}{2\,fr\sqrt{1+\varepsilon}} \tag{1}$$

Equation 2 gives the Length (L) of the patch in MPA

$$\mathrm{L} = \frac{C\sqrt{2}}{2\,fr\sqrt{\varepsilon r}} - 2\Delta L \tag{2}$$

The simulated image of the patch antenna in the High-Frequency Simulation Software (HFSS) tool is shown in Figure 3. Initially, the MPA is designed with a rectangular patch [19]; the substrate is glass with a dielectric constant of 5.5 at a design frequency of 4 GHz, yielding a return loss of around -10db. Then, it is tested on a FR4 as a dielectric medium with a dielectric constant of 4.4. The reflection coefficient is found to be -10.4, as shown in the table above.

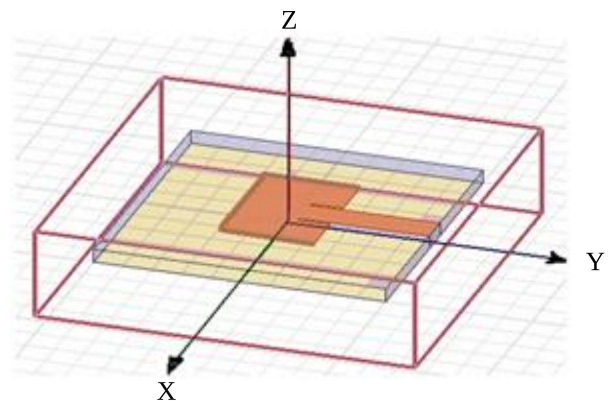

Fig. 3 Simulated structure of Rectangular Microstrip Patch Antenna (RMPA) using HFSS

4. Results and Discussions

Table 1 presents the results of designing a Microstrip Patch Antenna using various dielectric materials with variable dimensions. The parametric details of the incorporated dielectric material, the feeding method used and the type of simulation software employed in design-1.

In this case, the FR-4 substrate with a resonant frequency of 4.06 GHz produces a return loss of -6.4 dB, whereas glass epoxy operating at a resonant frequency of 4.1 GHz produces a return loss of -10.4 dB. It is observed that the antenna's bandwidth in the design is enhanced drastically by around 300 MHZ, which is phenomenal. In the proposed methodology, the simulated and measured return loss values display close agreement, a figure of merit.

5. Conclusion

The presented work has highlighted the progress in the MPA design. It further established that selecting the dielectric material and patch dimensions impacts the overall performance. This research further shows a link between various Microstrip Patch Antenna design aspects, including substrate material selection, geometrical configuration, feed techniques and bandwidth enhancement methods on the antenna's gain, return loss, directivity and reflection coefficient. Thus, it is established that the dielectric material selection and the patch's dimensions affect the patch antenna's performance. Apart from this, the scattering parameters of the designed antenna are enhanced to a higher degree.

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