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Research Paper

A comprehensive study on various geometries of microstrip patch antennas and its applications

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Abstract

Due to its low profile, ease of manufacture, and inexpensive behaviour, research on microstrip antennas has advanced significantly over the past few decades and is still a field that is alive and well. New radiating patches that may be manufactured and evaluated for usage in a variety of applications are designed with the aid of developing analysis methods and models. A simple and general geometry of each type of antenna shape has been considered for discussion. In terms of antenna size, dielectric materials, resonating band, peak gain, simulation tools, and their applications, symmetrically formed antennas are thoroughly reviewed in this study. Different geometry of microstrip patch antenna like flowers, leaves, trees, fans, and butterflies are covered in this article. Applications of microstrip patch antennas are also discussed in this paper.

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I. Introduction

Antennas are a crucial part of the communications sector. To put it more simply, it is a transducer that converts electrical energy into radio signals and radio signals into electrical energy. People who reside in remote areas can communicate with one another thanks to wireless communication technology, which allows for the transmission and receipt of signals. The microstrip patch antenna (MPA) shown in figure 1, which is popular due to its low volume, low cost, and low profile, is used in a wide range of applications today[1]. Antennas are becoming a more significant part of our daily life. During this time, more practical antenna technology also developed alongside advancements in mobile and cellular technology. Due to their portability, ability to operate at two or three frequencies, and tiny size, microstrip patch antennas have a promising future[2]. Additionally, they can accommodate both linear and circular polarisation.

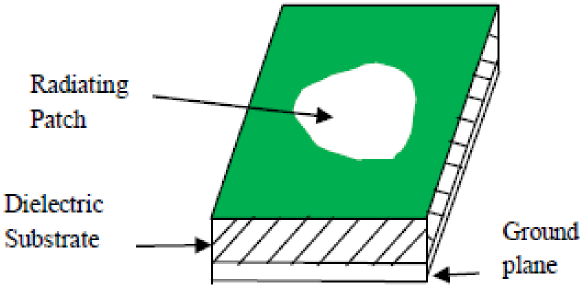

Figure 1: Configuration of microstrip antenna

By optimising the design of the microstrip patch antenna for a variety of various parameters, the performance of the antenna can be increased. At many different operating frequencies, a printed antenna can be used for wireless communication. Today's world of wireless communication is one that is quickly changing and always evolving. Multiple wireless service application types have evolved and grown significantly as a result of dual or multiband antennas. There have been a sizable number of design and development initiatives in the field of microstrip antennas that have been centred on application requirements. Predictable antennas and microstrip patch antennas are both prevalent types of antennas. Compared to microstrip patch antennas, predictable antennas offer better analysis and additional advantages[3]. We need an antenna that is very well organised and very compact in order to perform all of these wireless applications. Compared to traditional microwave antennas, microstrip antennas have more physical characteristics. They can be developed in a variety of geometrical sizes and shapes. Four main categories can be used to group all microstrip antennas as shown in Figure 2.

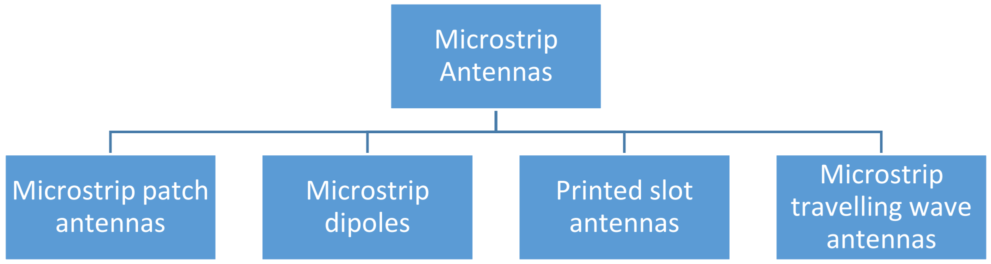

Figure 2: Types of micro strip antennas

For discussion, a straightforward and all-encompassing geometry of numerous antenna shape types has been taken into account. The next sections discuss the research of antenna forms, bandwidth augmentation methods, and antenna parameters including resonating band, bandwidth, gain, dimensions, and materials appropriate for different applications.

Microstrip patch antennas

A microstrip patch antenna (MPA) is made up of a ground plane on one side of a dielectric substrate and a conducting patch of any planar or nonplanar design on the other. It is a well-liked printed resonant antenna for semi-hemispherical coverage narrow-band microwave wireless communications. The microstrip patch antenna has received a great deal of attention and is frequently employed as a component of an array because of its planar configuration and simplicity of integration with microstrip technology[4]. The most basic and widely used microstrip antennas are rectangular and circular patches. These patches are employed in both the most straightforward and complex applications. Geometries that are rectangular are naturally separable, and their analysis is likewise straightforward. The symmetrical radiation pattern of circular patch antennas is a benefit. Figure 3 illustrates a rectangular microstrip patch antenna in its most basic configuration.

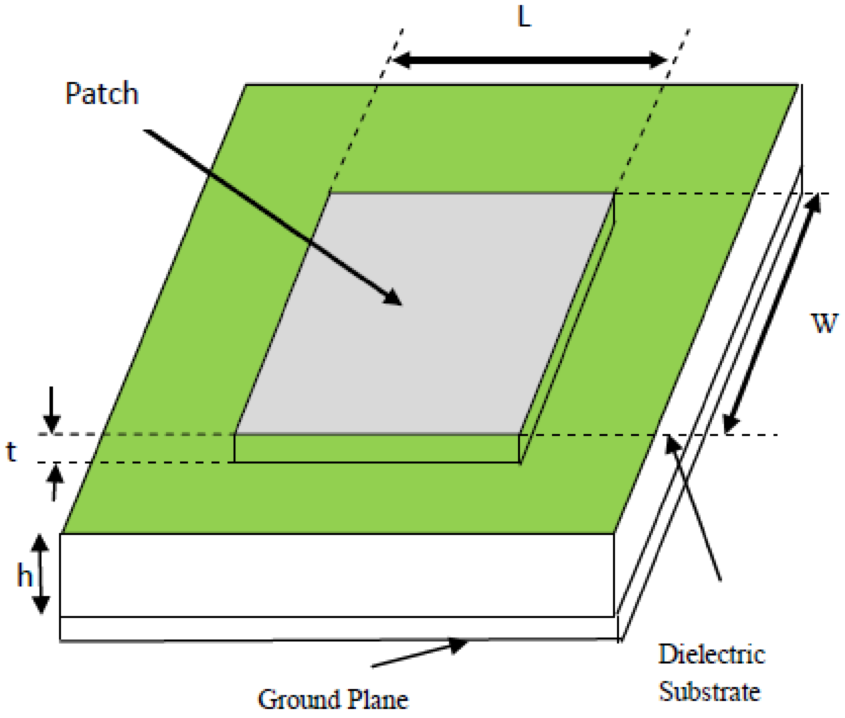

Figure 3: Microstrip patch antenna's rectangular structure

Feeding Methods

By direct or indirect contact, a feedline is utilised to generate radiation. The four most popular feeding methods are coaxial probe feed, microstrip line, aperture coupling, and proximity coupling[5]. Coaxial probe feeding is a feeding technique in which the outer conductor of the coaxial is connected to the ground plane and the inner conductor is attached to the antenna's radiating patch. Coaxial feeding has certain benefits, like simple assembly, low spurious radiation, and easy matching, but it also has some drawbacks, including a narrow bandwidth and challenging modelling, particularly for thick substrates.

One of the simpler fabrication techniques is microstrip line feed since it only requires a conducting strip to connect to the patch, which makes it possible to think of it as an extension of the patch. By adjusting the inset position, it is simple to model and straightforward to match. The drawback of this approach is that the bandwidth is constrained as substrate thickness grows due to an increase in surface wave and spurious feed radiation. Different feeding techniques are shown in figure 4.

Two distinct substrates are connected together in an aperture and separated by a ground plane. A microstrip feed line is located on the underside of the lower substrate, and its energy is connected to the patch through a slot in the ground plane that divides the two substrates[6]. This configuration enables separate feed method and radiating element optimisation. The bottom substrate often utilises a thick, low-dielectric-constant substrate, whereas the top substrate typically employs a thick, high-dielectric-constant substrate. The ground plane, which is in the centre, isolates the feed from the radiation source and reduces spurious radiation interference for pattern formation and polarisation purity. Benefits include the ability to independently optimise feed mechanism components.

The widest bandwidth and lowest spurious radiation are seen in proximity coupling. However, fabrication is challenging. The width-to-length ratio of the patch and the length of the feeding stub are utilised to regulate the match. It uses a capacitive coupling technique.

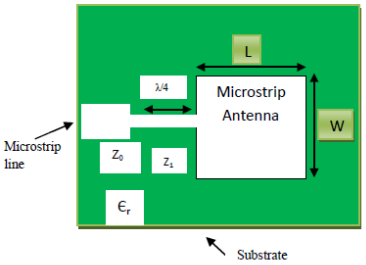 	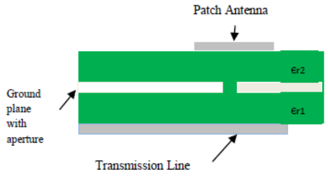 	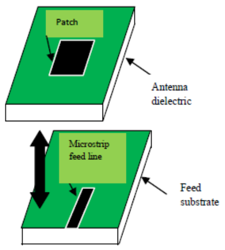
Microstrip line feed patch antenna	Aperture coupled feed patch antenna	Proximity coupled microstrip patch antenna

Figure 4: Different feed techniques of microstrip patch antenna

Different geometry of microstrip patch antenna

Miniaturised and multiband antennas are increasingly sought after due to technological advancements and the high need for the construction of tiny planar multiband antennas with simpler geometry for wireless devices [3]. Meandering, bending, folding, and wrapping are a few methods for miniaturisation. By modifying the ground plane and radiating patch with the use of fixed slots, reconfigurable slots, defective ground and notches, ground strip, etc., multiband operation is made possible[7]. The physical parameters of the antenna structure can be used to predict the resonating behaviour of a microstrip patch antenna. The antenna's geometry is naturally designed and may be tailored for use in a particular spectrum of applications.

Flower shape antennas

While the antenna published in [8] was built using air and copper substrates, the majority of the flower-shaped antennas in Table are designed utilising FR4 epoxy substrate. The antennas stated in [9, 10] function at a single resonating band, while the rose-shaped antenna[11] with a minimum area of 144mm^2 exhibits five band behaviour. The antenna indicated in [12] operates at a dual band. It's interesting to note that for flower-shaped antennas, the antenna with the maximum and minimum planar areas exhibits a bandwidth close to 500 MHz, suggesting that the area of the flower-shaped antennas in cases [11, 12] has little effect on the antenna's performance in terms of bandwidth. Figure 5 shows the flower shape antenna

Applications for antennas in the shape of flowers can be found in the frequency range of 1.03 to 13.46 GHz. The antenna indicated in [10] exhibits the largest bandwidth (11 GHz). The antenna with the smallest size (12 *12mm^2) is described in [11]. In the E-plane and H-plane, the radiation pattern of the flower-shaped antenna exhibits nearly bidirectional behaviour. Higher resonance frequencies are generated by the longer current path.

As a result, a flower-shaped antenna is a better contender for wideband applications than a conventional antenna.

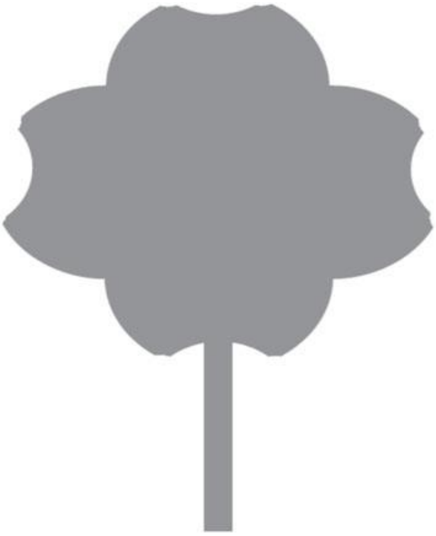

Figure 5:Flower shape antenna geometry

Leaf shape antennas

The antenna reported in [13]has the largest planar area, but two antennas[14, 15] been designed using FR4 epoxy substrate material, are resonating at a single band, and have the same smallest antenna dimension (25 *16 and 20* 20mm^2). Antennas with minimum planar areas [14, 15] display bandwidths of 3 and 4 GHz, respectively, whereas those with maximal planar areas [13] achieve the highest bandwidth of 28.4 GHz. We find that the huge planar area and change in dielectric constant from 4.4 (FR4 epoxy) to 3.5 produce a greater bandwidth of 28.4 GHz in leaf-shaped antennas. The ratio of the antenna's maximum area to its minimum area is 16:1, but the ratio of the antenna's largest area to its smallest area [13] is 7.1:1. It follows naturally that the bandwidth will rise as the antenna area does. The daunt form pattern, omnidirectional pattern, asymmetrical and unidirectional pattern, and broadside pattern are all visible in the radiation pattern of the leaf-shaped antenna shown in figure 6.

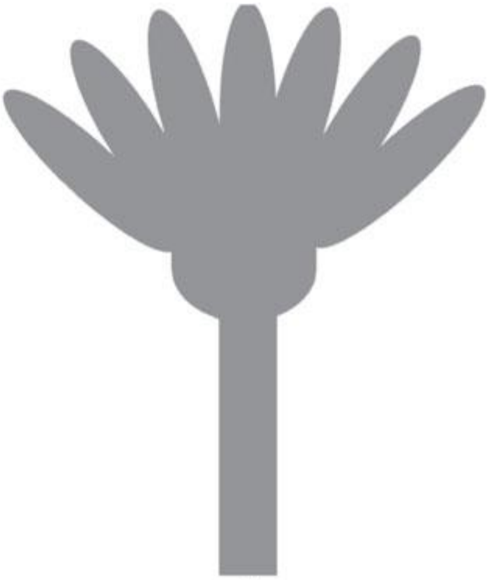

Figure 6: Leaf shape antenna geometry

Tree shape antennas

The Pythagorean shape antenna reported in[16, 17] is a multiband antenna, while the remaining antennas [18–20] are single-band antennas. Among the reported antenna in [17, 19, 21], the antenna published in [21] has the largest area (150 *150 mm^2) while the antenna described in [22] is less in size. While antenna [21] produces a very low impedance bandwidth (0.7 GHz) as a result of its vast size, the antennas indicated in [19, 22] have smaller patch areas and give larger bandwidth of the order of 17.3 GHz [19] and 11.2 GHz [22].

The majority of the antennas [21–23] are found to fall under the category of fractal antennas as a result of the examination of tree form antennas. After filling the empty space with conducting material, the fractal antenna lengthens the effective current path on the radiating surface. As a result, fractal geometry can take the place of tree form geometry in wideband applications, and vice versa. Tree shape antenna geometry is shown in figure 7

Figure 7:Tree shape antenna geometry.

Fan shape antennas

The smallest compact antenna, with a maximum measured bandwidth (14.6 GHz), has been reported in [24] and is suitable for ultra-wide band applications. The antenna reported in [25] with the biggest planar area of 125 *125 mm^2 has an extremely narrow bandwidth (simulated) of 0.49 GHz. However, since only the simulated bandwidth of the antenna with the largest area [25, 26] is presented, it is challenging to determine a direct correlation between the size and the bandwidth. In [25, 27], a maximum simulated gain of 6 dBi and a maximum measured gain of 4.4 dBi are noted. The fan-shaped antenna emits radiation in an omnidirectional, bidirectional, and dipole-like pattern as shown in figure 8.

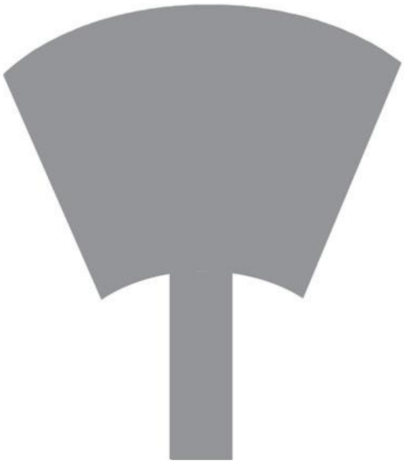

Figure 8: Fan shape antenna geometry

Butterfly shape antennas

Despite the fact that the butterfly shape antenna (figure 9) is not frequently mentioned in the literature, the authors searched it and only discovered one single band butterfly shape antenna. Antennas[28, 29] have a measured bandwidth of 2.21, 6.7, and 1.45 GHz, respectively. These antennas' operating frequencies range from 2.6 to 9.3 GHz. Although butterfly-shaped antennas[30]have been proposed for low frequency applications, their huge structure size (>27 $*34mm^2$) prevents them from being realistically integrated in compact devices.Table 1 shows the comparative analysis of different patterns on various parameters like resonating bandwidth, peak gain (dBi), tools used with the antenna size.

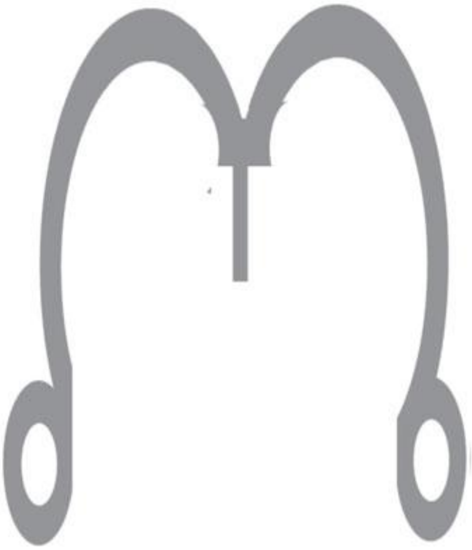

Figure 9: Butterfly shape antenna geometry

Table 1: Comparative analysis of different patterns of microstrip patch antennas

Antenna shape and size (mm^2)	Substrate	(Resonating band)/bandwidth (GHz) at −10 dB scale	Peak gain (dBi)	Tools used/ applications	Reference
Flower shape 28 × 41.8	FR4 epoxy	(2.2–10.6)/8.4 M	5 M	HFSS/wireless, microwave imaging system	[9]
Flower shape 34 × 39.1	FR4 epoxy	(2.1–11)/8.9 M	5.03 S	Bidirectional/ omnidirectional	[31]
Leaf shape 30.5 × 35.5	RT/Duroid	(3–14)/11 M (5–6) NB	6 S	HFSS, CST/ UWB application	[32]
Leaf shape 80 × 80	εr = 3.5, h = 1.5	(1.3–29.7)/28.4 M	4 M	CST/L, C, X and Ku band application	[13]
Tree shape 50 × 80	FR4 epoxy	(0.92–1.06)/0.14 M	NR	HFSS/RFID	[18]
Tree shape 50 × 60	FR4 epoxy	(1.64–9) M reconfigurable	NR	HFSS/WLAN, WiMAX	[17]
Butterfly shape 27 × 34	RT/Duroid 5880	(6.02–7.47)/1.45 M	8.8 M	CST/C-band	[29]
Butterfly shape 80 × 80	Metal, air	(4.15–6.36)/2.21 M	8.3 M	HFSS/RFID, wireless	[30]
Fan shape 125 × 125	RT/Duroid, FR4 epoxy, foam	(1.12–1.61)/0.49 S	6 S	NR/L-band GPS satellite communication	[25]
Fan shape 30 × 35	FR4 epoxy	(3.1–10.6)/7.5 M	4.4 M	HFSS/UWB applications	[27]

Applications

The performance, sturdiness, ease of production, and wide use of Microstrip patch antennas are widely known. The advantages of this Microstrip patch antenna outweigh its drawbacks, which include its simplicity in design and light weight, among others[33]. It finds use in a variety of settings, including satellites, rockets, aircraft, missiles, and obviously military systems. Due to their low cost of substrate material and production, microstrip antennas are currently widely used in many fields and regions and are seeing a boom in the commercial sector. Applications for microstrip patch antenna are numerous. Following is a discussion of a few of these applications:

Global Positioning System applications: The current generation of global positioning systems uses microstrip patch antennas with substrates made of sintered materials with high permittivity[4]. Due to their placement, these circularly polarised, small, and costly antennas are rather expensive. It is anticipated that the general public would employ millions of GPS receivers to help land automobiles, aeroplanes, and maritime vessels precisely determine their whereabouts.

Worldwide Interoperability for Microwave Access (WiMax): WiMax is the trade name for the IEEE 802.16 protocol. Theoretically, it has a 30 mile range and a 70 Mbps data rate. Due to the fact that MPA produces three resonant modes at 2.7, 3.3, and 5.3 GHz, it can be employed in WiMax-compliant communication devices[4].

Mobile and satellite communication application: Small, affordable, and low profile antennas are necessary for mobile communication. All specifications are met by microstrip patch antennas, and numerous varieties of microstrip antennas have been developed for use in mobile communication systems[34]. Circularly polarised radiation patterns are necessary for satellite communication and can be achieved using either a square or circular patch with one or two feed points.

Radio Frequency Identification (RFID): RFID is used in a variety of industries, including manufacturing, transportation, logistics, and health care. Depending on the requirements, RFID systems typically operate from 30 Hz and 5.8 GHz in frequency[35]. A tag or transponder and a transceiver or reader are the basic components of an RFID system.

Radar Application : Radar can be used to find moving objects, including people and cars. The microstrip antennas are the perfect option because it calls for a low profile, lightweight antenna subsystem[35]. In comparison to conventional antennas, the fabrication process based on photolithography enables the mass manufacture of microstrip antennas with reproducible performance at a cheaper cost in a shorter amount of time.

Telemedicine Application: Antennas used in telemedicine applications operate at 2.45 GHz. Wireless Body Area Network (WBAN) is suited for wearable microstrip antenna. The proposed antenna outperformed the other antennas in terms of gain and front-to-back ratio. It also has a semi-directional radiation pattern, which is preferable to an omni-directional pattern for preventing unnecessary radiation from reaching the body of the user, and it meets the requirements for both on-body and off-body applications. Telemedicine applications can benefit from an antenna that resonates at 2.45GHz, with a gain of 6.7 dB, and an F/B ratio of 11.7 dB[4].

Rectenna Application : Rectenna is a rectifying antenna, a unique kind of antenna that transforms microwave energy straight into DC electricity. Antenna, ore rectification filter, rectifier, and post rectification filter are the four components that make up the rectenna. To address the needs of long-distance communications, rectenna applications require the design of antennas with extremely high directional qualities. The antenna's electrical size must be increased in order to achieve the goal of using it to transmit DC power across wireless networks over a long distance[4].

Medicinal applications of patch : Microwave energy is claimed to be the most effective method of producing hyperthermia in the treatment of malignant tumours. The design of the specific radiator that will be utilised for this function needs to be lightweight, manageable, and robust. These requirements can only be met by the patch radiator. Printed dipoles and annular rings with S-band patterns served as the foundation for the original designs of the Microstrip radiator used to induce hyperthermia. Later, the concept was built around an L-band circular microstrip disc. The instrument has a straightforward operation; it measures the inside body temperature of human by coupling two Microstrip lines and separating them with a flexible separator[35].

II. Conclusions

It is obvious that these types of antennas have already been created using advanced technology and intricate designs. Due to the steady increase in communication users and the never-ending search for increased wireless communication bandwidth. It is necessary to create antennas with broad and compact capabilities.The analysis of several antenna geometries, in particular antennas with flower, leaf, tree, fan, and butterfly shapes, led to the conclusion that the radiating patch edges of these shapes are notched to increase the antenna's perimeter and impedance bandwidth.This claim is supported by the observation that the radiating patch's edges, not its centre, exhibit a maximum current distribution.The total input impedance of the patch antenna determines the resonance behaviour of the microstrip antenna, and any physical modification to the antenna construction can modify the input impedance.

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