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A Review on Novel Microstrip Patch Antenna Designs and Feeding Techniques

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Abstract

Mobile technology is rapidly advancing nowadays due to its high impact in our day-to-day lives. As a result, there is an increasing need to study the advancement of antenna systems, which are regarded as fundamental equipment for wireless connectivity. Compared to the traditional large size antennas, microstrip patch antennas are now widely used in different applications such as smart phones, military, smart wearable devices etc. due to its unique characteristics such as lighter weight, reconfigurable structure, foldability, ease of fabrication, multi-frequency operations, and compactness. This research study presents a review on various microstrip patch antenna designs and the different antenna feed mechanisms available for 5G applications.

Keywords: Compact antenna design, microstrip antenna, antenna feed mechanisms, multi-frequency band antenna

1. Introduction

With the ever-increasing demand for communication technologies in the world, the data consuming modern devices such as wireless sensors, smartphones, gadgets and automation systems will cause a shortage of bandwidth. This necessitates the need to advance the wireless networks to satisfy the emerging bandwidth requirements. As a result, 5G technology has been widely incorporated to make use of higher frequency bands and a wider signal bandwidth [2]. A patch antenna has optimal gain and a comparatively narrow bandwidth. A patch antenna includes a metal patch levitated over a ground plan, which is separated by a dielectric material. They are simple to design and manufacture, and have largely replaced traditional antennas in almost all of the mobile and wireless applications. Microstrip patch antennas [1] have been the most rapidly evolving structures in the antenna

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research over the recent years. This advancement of microstrip patch antenna on diverse applications across the globe has led to the development of several advanced versions of microstrip patch antenna in the last 15 years. As a result, these antennas have quickly progressed from academia to real-time applications, with applications in a wide range of real-time microwave systems.

The traditional microstrip patch antenna is made up of a patch on the top side of the antenna's dielectric substrate and then a ground plane on another side of the antenna's substrate. These two are usually fed by a microstrip line or using a co-axial probe. Recently, the ultra-wideband microstrip patch antennas [3] have gained increasing interest due to its different advantages over traditional antenna elements such as reflectors, cord, horn or slot antennas. This type of microstrip antenna [4] also has significant advantages over other antenna systems, including ease of use, lightweight, simple fabrication, enhanced connectivity, cost effectiveness, etc.

The research study presents a general architecture of microstrip patch antenna and its different types. The next section introduces the different types of microstrip patch antenna designs such as stacked antenna, L-Probe antenna, and reconfigurable E-Shaped patch antenna. Further, the next section discusses about the available compact designs and the suitable frequency range. The preceding section compares the different feeding mechanisms of microstrip path antenna. The last section summarizes the proposed research study by stating the future research directions.

2. General Architecture of Microstrip Patch Antenna

In 1953, a research theory has been proposed to design and develop microstrip patch antennas but the first real-time microstrip patch antenna has been developed in 1970 [6] by including a radiating patch on the top side and a ground plane on the bottom side of the substrate [7].

Microstrip antenna has various advantages such as compactness, reduced weight and volume with easy fabrication technology [8]. Microstrip patch antennas have significantly grown as the demand for relatively small and lower-profile antennas has increased in the domain of personal and mobile communications. Apart from its numerous advantages, it also has some drawbacks, such as narrow frequency band, reduced efficiency, increased Q-value, and low polarization [9].

Figure 1 shows the general representation of microstrip patch antenna integrated on a blue colored material (dielectric) with a grey colored ground plane. The upper patch portion forces the electromagnetic waves to propagate at a specific frequency. The patch's length and width are defined by the frequency of operation and the attributes of the utilized dielectric material.

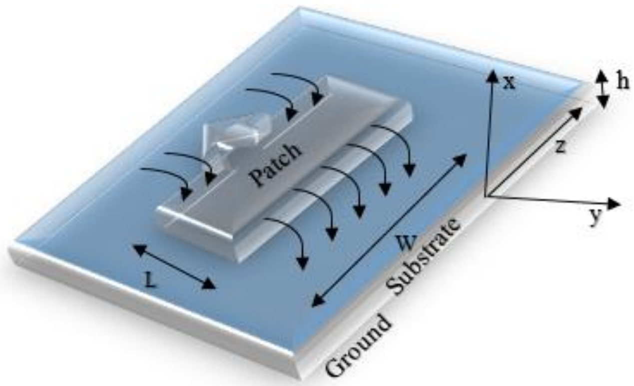

Figure 1. General Rectangular Microstrip Patch Antenna Architecture

The commonly used dielectric materials in a microstrip patch antenna are Fr4 and RT-Duroid [10, 11]. The properties of those dielectric materials are discussed below.

Table 1. Properties of dielectric materials

Properties	**RT-Duroid**	**Fr4**
Surface resistivity (MOhm)	3 X 10^7	2 X 10^5
Volume resistivity (M-Ohm.cm)	2 X 10^7	8 X 10^7
Dielectric constant	2.3	4.38
Density (kg/m3)	2202	1850
Breakdown voltage	~ 62 kV	56 kV
Loss tangent	0.0003	0.011
Peel strength (N/nm)	5.7	9.2

The effective dielectric constant of the utilized substrate is given as:

$$\epsilon_{reff} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2}\left[1 + \frac{12.h}{W}\right]^{-1/2}$$

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The length and width of the modified rectangular patch can be calculated by using the below mentioned mathematical expression [11, 20]:

$$W = \frac{c}{2.f_{rf}\sqrt{\frac{\varepsilon_r + 1}{2}}}$$

$$L_{eff} = \frac{C}{2f_{rf}\sqrt{\epsilon_{reff}}}$$

$$L = L_{eff} - 2\Delta L$$

$$\Delta L = 0.412h\frac{(\varepsilon_{reff} + 0.3)(\frac{W}{h} + 0.263)}{(\varepsilon_{reff} - 0.257)(\frac{W}{h} + 0.8)}$$

Where,

f_{rf} = Resonant Frequency, ε_r = Dielectric Constant, c = Speed of Light (3×10^8)

3. Microstripline Coupled Antenna Aperture

This method of feeding microstrip patch (or printed dipole) antennas eliminates the need for a direct link between antenna and its feedline. Replacing the electromagnetically coupled antenna, this method involves two different substrates differentiated by ground plane. The radiating element is located on one substrate, while the feed network is located on other substrate [13].

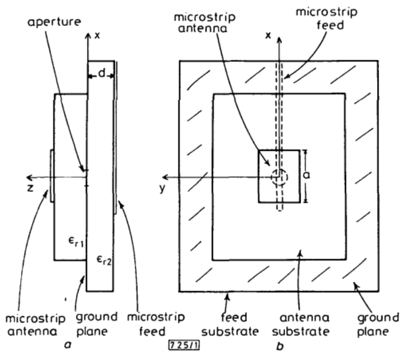

Figure 2. Microstripline Coupled Antenna Aperture [13]

4. L-Probe Fed Patch Antenna

The horizontal side of the probe, which lies near to the patch, produces an additional resonance. It also provides the ability to combat the probe's responses. Only one layer and one patch is available in this type of patch. The typical bandwidth of the substrate is ~30% [14].

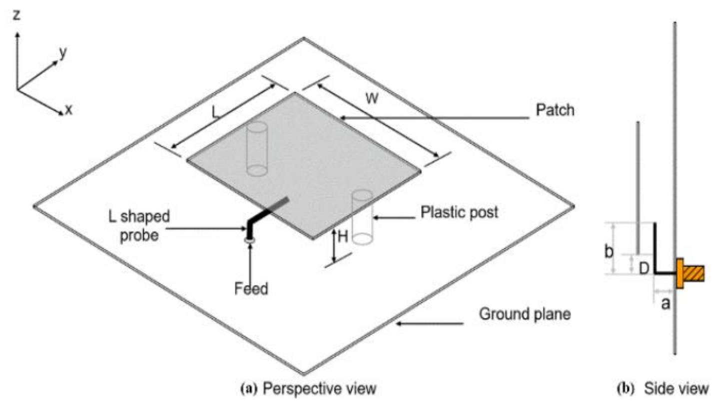

Figure 3. L-Probe Fed Patch Antenna [14]

5. Reconfigurable E-Shaped Patch Antenna

The E-shaped reconfigurable antenna includes two RF PIN diodes at optimized positions. As a result, if one switch is turned ON obviously the other will be turned OFF and further the unequal lengths of the two slots result in circular polarization. With the symmetrical structure, the different states of the switches get reversed and as a result the circular polarization (CP) with reverse orientation will be obtained at same frequency band [15]. A reconfigurable network and a complex bias circuit are not included in this design.

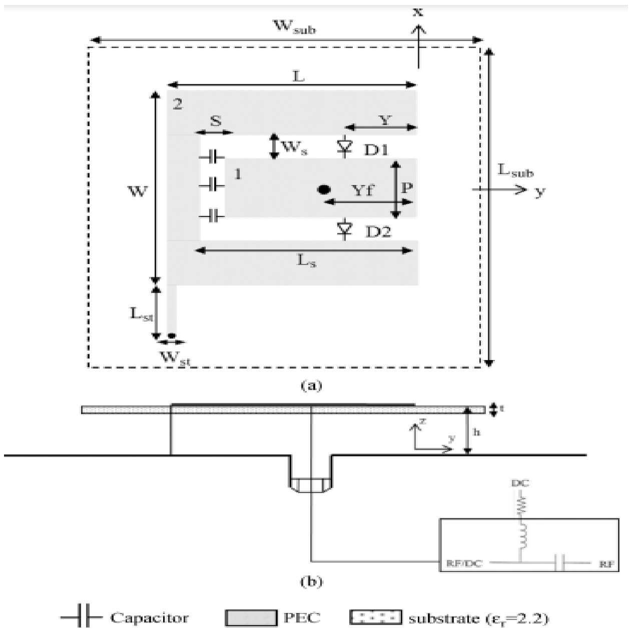

Figure 4. Reconfigurable E-Shaped Patch Antenna [15]

5.1 Suitable Frequency Range

As the microstrip patch antennas are widely used in a variety of effective applications in the field of communication, many applications cover a wide range of frequencies ranging from MHz to GHz. Additionally, different factors will influence the real-time operating frequency range of microstrip patch antenna [16]. At lower frequency region, the antenna properties such as weight and size will be considered as limitations, whereas at the higher frequency region, the tolerance and electrical loss will be considered as limitations.

The minimum frequency used for designing a microstrip patch antenna is 450 MHz [17]. With the exceptional signal propagation properties, microstrip patch antenna has become ideally suitable for rural communication. The maximum frequency used for designing a microstrip patch antenna is 60 GHz [18], where the patch dimensions are obtained by using a size extension method.

5.2 Feeding Mechanisms

Some of the important feeding mechanisms of microstrip patch antenna [19] are:

- Coaxial Probe Feed

It is one of the popular method used for feeding microstrip patch antennas. The coaxial connector's inner conductor passes through the dielectric and is welded to radiating patch, while the outer conductor connects to ground plane. The feed can be placed anywhere inside the patch to suit the input impedance.

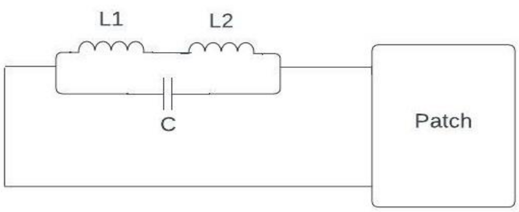

Figure 5. Circuit diagram of Coaxial Probe Feed

- Microstrip Line Feed

This technique directly connects a narrow conducting strip to the microstrip patch's edge. This arrangement allows the feed to be imprinted on the same substrate as a planar structure. However, the ever-increasing dielectric substrate thickness also increases the radiation generated by the feed. With a simple planar structure, the antenna's bandwidth will also be reduced by 2-5%.

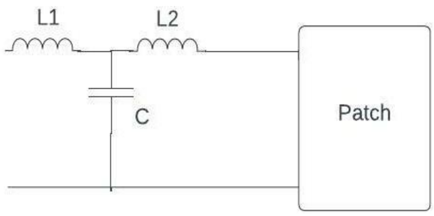

Figure 6. Circuit diagram of Microstrip Line Feed

- Proximity Couple Feed

A coupling capacitor is serially connected with the RLC resonant circuit. This can be achieved by performing impedance matching and tuning the bandwidth. The feed's open end will provide stud, which results in enhancing the bandwidth. This technique has achieved 13% bandwidth. Even though two layers are used to increase the bandwidth and reduce the unwanted radiation, it is highly difficult to implement a proper alignment.

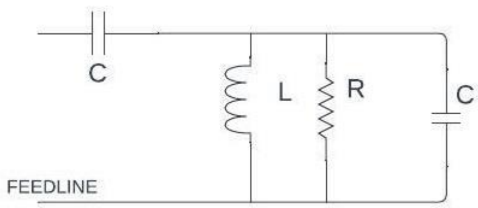

Figure 7. Circuit diagram of Proximity Couple Feed

- Aperture Coupled Feed

In this technique, ground plane separates microstrip feed line and radiating patch. The patch and feed line are connected via aperture in the ground plane. The coupling will vary depending on the aperture's size, i.e. length and width to optimize broader bandwidths and lower return losses. With the symmetrical configuration, the coupling aperture is usually centred beneath the patch, resulting in lower cross-polarization. Since the ground plane separates patch from feedline, tendentious radiation is reduced.

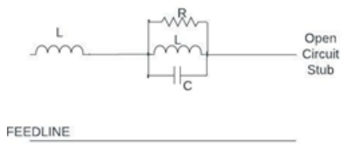

Figure 8. Circuit diagram of Aperture Coupled Feed

The other recently proposed microstrip patch antennas' feed mechanisms are tabulated below in Table 2.

Table 2. Recent techniques on microstrip patch antennas' feed mechanisms

References	Feed Technique Applied	Proposed MPA model	Gain (dB_i)	Dielectric Constant (ε_r)	Bandwidth (GHz)
[20]	Series-feed method	Broadside Array antenna	15.2	2.3	0.7
[21]	Inserted method	32-Elements based patch antenna	21.3	2.3	1.14
[22]	Coplanar slot	Parasitic Element based microstrip antenna	6.9	4.3	1.63
[23]	PSA-CO	Swarm intelligence based microstrip antenna	10.62	2.3	0.42
[24]	Aperture-Couple feed	Void substrate based waveguide driven square microstrip antenna	11.82	3.64	2.7
[25]	Probe feed	4×2 microstrip array antenna	16.3	2.3	0.92

6. Summary, Conclusion and Future Research Directions

The antenna discipline has had a very productive time frame in engineering over the recent years. The recent technological improvements in certain novel antennas, such as broadband, multiband, reconfigurable structures, millimetre wave antennas have contributed compactness, enhanced bandwidth, and high gain characteristics to its success. From the study it is observed that the feeding technique plays a major role in decision making process of microstrip patch antenna as it influences the significant antenna characteristics such as return loss, patch size and bandwidth. Different microstrip patch antenna designs have different gain, efficiency and bandwidth. It is also observed from the analysis that the aperture coupling feed is the best performing feed technique in the field of microstrip patch antenna. Furthermore, the recent advancement of 5G and B5G technologies have generated a significant impact on the different radiating elements of the antenna. Despite the hype, there are still several issue to be resolved to achieve miniaturization of microstrip patch antenna. The future research work will be more focused on modifying the feeding technique in order integrate with the advanced 5G applications.

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