Multi-Frequency Microstrip Patch Antenna - A Review on its Design and Applications

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ABSTRACT
The preliminary objective of this review analysis is to discuss the prominent design aspects of microstrip patch antennas. The transformation in the wireless communication devices has led to the increased demand of lightweight and compact antenna designs. In this consideration, the development of microstrip patch antennas has come into prominence. This review analysis discusses the prominent design aspects of microstrip patch antennas along with the effect of dielectric substrate on antenna parameters. The study discusses different feeding techniques and their influence on parameters such as bandwidth, size, and impedance matching. A comparative analysis is provided to discuss the influence of various substrates and feeding techniques on antenna parameters.

Keywords
Microstrip Patch Antenna, Dielectric substrates, Wireless communication, Bandwidth, frequency

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1. Introduction

1.1 Background of the study:

Recent decades has seen significant transformation in wireless technology in terms of its mode of operation, frequency of allocation, size of the wireless devices and various processes involved in improvement and enhancement of the robustness of the wireless systems (Karli & Ammor, 2014) [1]. Due to the robustness and potential of the wireless systems, there has been a great demand for the wireless devices. Furthermore, with the development of modern and advanced wireless standards, wireless devices have transformed themselves in terms of compactness and by incorporating multi-functional aspects in these devices (Bao & Ammann, 2014) [2]. Antennas are considered as one of the intrinsic and innate components of these wireless devices. The compactness of the wireless systems has given rise to the development of lightweight and compact antennas which are widely used in wireless transmission (Kumar et al., 2014) [3]. These lightweight antennas are gaining more prominence because of their easy integration into various radio frequency (RF) bands. Hence, the demand for these antennas which can cover multiple indistinct homogeneous and heterogeneous frequency bands in a wireless system has increased prominently (Zhu et al., 2018) [4]. Though lightweight antennas are suitable for wireless communication, it was observed that these small and lightweight antennas reduce the efficiency, gain, and bandwidth of the transmitted signals which is a significant issue in communication devices.

With advanced multi band attributes required by various wireless communication devices, it is challenging for the antenna engineers to design antennas which are robust, stable, reliable, efficient, compact, and cost-effective. Besides, it involves a lot of complexities to design the antennas which have sufficient bandwidth to support multiple frequency bands (Khan et al., 2015) [5]. Multiple technologies and mechanisms have been proposed by the researchers for enhancing the bandwidth, efficiency, and gain of the wireless devices using different antenna designs (Midasala & Siddaiah, 2016) [6] (Verma et al., 2016) [7]. In order to overcome the challenges related to antenna design, microstrip patch antennas were developed which are advantageous with respect to modeling and fabrication, cost, and compactness (Marotkar & Zade, 2016) [8]. These microstrip antennas are developed based on circuit modeling and time domain based electromagnetic technologies. The potential of the MPAs are improved by performing optimization using parametric analysis. These MPAs are profoundly implemented in real time wireless communication devices such as bluetooth devices, industry specified medical devices, and mobile communications (geetanjali & Rajesh, 2017) [9]. The MPAs possess certain superior characteristics such as reduced size, stability towards different frequency bands, multi-frequency communication, low cost, and simple fabrication makes it a suitable candidate for different portable communication gadgets such as mobile phones, laptops, and navigation devices which use wireless access points. Improvement of these features and to create multiband antennas are considered as one of the prominent design considerations of MPAs for wireless communications (Amjad et al., 2018) [10] (Gnanamurugan & Sivakumar, 2019) [11]

1.2 Microstrip Patch Antennas:

MPAs were initially introduced in 1953; However, the first practical microstrip patch antennas were developed by Munson and Howell in the year 1975 (Howell, 1975) [12]. The general form of MPA is designed with a radiating patch on one side of a dielectric substrate, and a ground plane on the other side of the substrate (Lee, 2016) [13]. These antennas are advantageous compared to conventional antennas in terms of small volume, reduced size and weight, and simpler fabrication using printed circuit technologies (PCB). These smaller antennas are profoundly used in mobile and personal communication devices because of their superior characteristics (Reddy et al., 2017) [14]. However, irrespective of its advantages, the adaptability of the MPAs are restricted due to certain limitations such as high value of Q value, narrow frequency band, low power, low efficiency, inefficient scan performance, appalling polarization polarity, and spurious feed radiation (Rana & Sharma, 2018) [15]. Microstrip patch antennas are available in divergent dimensions such as slotted, triangular, circular, and rectangular. A schematic representation of a basic structure of a rectangular patch antenna printed on a dielectric material is illustrated in figure 1.1.

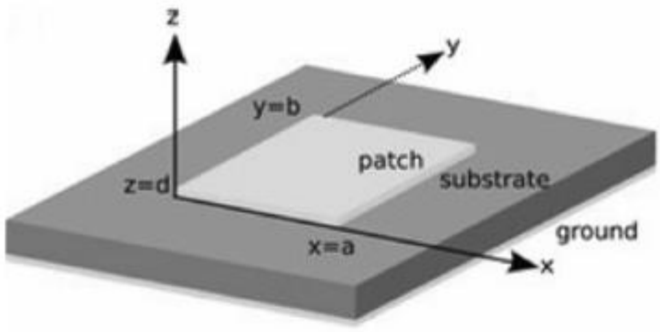

Figure 1.1 Basic structure of a patch antenna (Bansal & Gupta, 2020) [32]

The structure of the patch antennas is printed on a dielectric material and the ground plane is illustrated in figure 1.1. The dielectric material is represented in the form of white patch on the top surface of the circuit board and the ground plane at the bottom is denoted in gray colour. The white patch on the upper portion of the board is the original printed patch on the dielectric substrate which instigates the radiation through electromagnetic waves for a particular frequency. The dimension of the patch antenna (length and width) is highly influenced by the operating frequency and properties of the dielectric materials. Some of the commonly used dielectric materials in the design and fabrication of MPAs and their respective properties are discussed in the table1 below. (Bansal & Gupta, 2020) [32] (Parmar et al., 2014) [16]

Table 1. Various dielectric materials and their properties

Parameters	**Fr4**	**RO-4003**	**RT-Duroid**
Volume Resistivity (M-Ohm.cm)	$8 * 10^7$	$1700 * 10^7$	$2 * 10^7$
Density (kg/m^3)	18.50	1790	2200
Breakdown Voltage	55 kV	-	> 60 kV
Peel Strength (N/nm)	9	1.05	5.5
Dielectric Constant	4.36	3.4	2.2

Surface Resistivity (M-Ohm)	2 * 10^5	4.2 * 10^9	3 * 10^7
Tensile Strength (MPa)	310	141	450
Water Absorption (%)	< 0.25	0.06	0.02
Loss Tangent	0.013	0.002	0.0004

Different types of dielectric materials are used for printing antennas and are easily available in the market. Each and every dielectric materials are incorporated with their own distinctive features, functionalities, different conduction properties and with different dielectric constants, etc. These special properties of the dielectric materials influence the communicating waves in the patch antenna and enhance the functional attributes of the microstrip antenna (Abdulhameed et al., 2018) [17] (Jain & Dwivedi, 2016) [18]. The influencing properties of the dielectric materials and different types of dielectric materials are tabulated in table 1. Other types of dielectric materials which are prominently used in antenna designs are variants for Taconic, TR-Duroid etc. The dielectric materials are selected based on their application and fabrication cost (Zulkifeli, et al., 2017) [19]. Among different shapes of MPAs, rectangular shaped MPAs are simpler in design and are profoundly implemented in the fabrication and implementation of MPAs (Kiruthika & Shanmuganantham, 2016) [20].

1.3 General attributes of Microstrip patch antennas:

The characteristics and functionalities of the MPAs for various shapes such as annual-ring, equi triangular and rectangular antennas are discussed in detail in (Bhoot et al., 2019) [21] (Lee & Tong, 2012) [22]. There are various characteristics which are essential to analyse the basic geometry of the MPAs, irrespective of the patch shapes. These characteristics essays a prominent role in the fabrication and implementation of microstrip antennas.

- MPAs possess multiple and indefinite resonant stages wherein the resonant frequency is defined and controlled by the thickness of the dielectric substrate, relative permittivity of the substrate ε_r, and the shape and size of the antenna patch. For an instance, if a rectangular patch is considered for the antenna design with dimensions a and b, the corresponding resonant frequency is given as shown in equation 1. (Lee & Tong, 2012) [22].

$$f_{mn} = \frac{k_{mn} c}{2\pi\sqrt{\varepsilon_r}} \quad ..... (1)$$

Where f_{mn} is the resonant frequency and $k_{mn} = [(m\pi/a)^2 + (n\pi/b)^2]^{1/2}$.

- Due to the occurrence of the fringing fields at the edges of the antenna patch, the dimension of the patches seems to be enlarged and semi-empirical aspects are found in the cavity-model-based antenna designs for achieving appropriate dimensions. It must be noted that these factors differ from one patch to another.
- Every resonant mode possesses unique functional radiation patterns and the prominently adapted stages are (1, 0) or (0, 1). These two stages are potentially robust and the patterns in these modes are broad with half-power beamwidths of the order of 100^o. The gain of the antennas are approximately 5 dB and exhibits linear polarization. Also, by using these two modes with relevant patterns, circular polarization can also be obtained.
- The input impedance in coaxial-fed antennas depends on the position of the feed. The changes in the input resistance at resonance with feed position follows the position of the cavity field. When the position of the feed is nearer to the patch edge, the input resistance is slightly higher and it decreases when the feed position is inside the patch. The range of input resistance varies from few tens to hundred ohms.
- For coaxial-fed antennas, the resonant resistance can be maintained in line with the feedline resistance by selecting the appropriate feed location. Implementation of thin substrates in antenna design with thickness less than or equal to 0.03 λ_o ,

will reduce the inductance of the feed at resonance. This helps the voltage standing wave ratio (S) to obtain unity value. The value of S increases with the deviation in the resonant frequency. In case of linear polarization, the bandwidth of the impedance is defined as the frequency range for which the value of S is less than or equal to two, for a 10 dB return loss. This range is similar to that of the antenna bandwidth. In case of circular polarization, the bandwidth is evaluated using the values of $S \leq 2$ and with an axial ratio ≤ 3 dB.

- In MPAs, it is observed that the impedance bandwidth increases with elevation in the thickness of the dielectric substrate and is inversely proportional to the square of relative permittivity i.e. $\sqrt{\varepsilon_r}$. However, the selection of substrates with low permittivity can result in increased radiation levels from the feed lines. Whereas for high permittivity substrates, the increased thickness of the dielectric substrate leads to the reduction in efficiency because of the generation of the surface wave.

2. Related Works:

The research related to microstrip antennas have gained vast significance in recent times due to its significance in portable and wireless communication devices. This section describes some of the prominent related works on MPAs.

(Mezall, 2016) [23] proposed a novel design for multi-band antennas based on patch resonators. The design of MPAs were derived from the transformed first iteration of Minkowski fractal geometry and a small square cut was applied at the centre of the antenna for two conditions: with and without incorporating corner square patches. These two antennas were fabricated with dual feeds and single layer for operating it for multiple frequencies. A Fr4 dielectric substrate was used for designing with a height of 1.6 mm and with a dielectric constant of 4.4. It was observed from the analysis that the MPAs with corner patches and with the same characteristics performed well and exhibited more operational frequencies in comparison with antennas without corner patches. Results validated the efficacy of this antenna design which possessed dense and compressed dimensions with improved return loss and enhanced radiation patterns that are widely employed in various communication devices.

(Sun, 2019) [24] presented a wideband intensification technique based on the multimode evaluation of MPAs. In his technique, certain appropriate shorting loads were added on the patch and different modes of high order resonant frequencies such as TM 20 - TM 50 were reduced and integrated with the highest frequency mode TM 10. These resonant modes allow the antenna to operate with a wide band. Employing the proposed bandwidth enhancement techniques, a UWB patch antenna with compact design, circular polarization, and unidirectional radiation was designed. The patch size was selected as $0.5\lambda_o \times 0.5\lambda_o$ and the height was maintained at $0.1\lambda_o$ where λ_o is defined as the wavelength of free space at the center frequency. Results from the experimental analysis and simulation showed that the design of the proposed approach possessed a BW of 85% for S11 which is less than -10 dB and observed a RHCP gain greater than 6 dBic ranging from 2.2 to 5.5 GHz which showed that the current antenna design was appropriate for applications requiring an ultra wideband CP patch antennas.

(Rajan & Vivek, 2019) [25] designed rectangular patch antenna with microstrip-line inset-fed with reduced return loss for wireless devices. The patch antenna was designed as a two layered electromagnetically coupled antenna in order to resolve the limitations of conventional patch antennas such as narrow BW, poor directivity, reduced efficiency and gain. The proposed antenna was operated at a frequency of 77.32 GHz. . It was inferred from the results that the designed antenna achieved a very minimal loss which shows that the antenna is very efficient with low power loss and superior impedance matching. The compact size with better return loss and improved radiation pattern makes it adaptable for various complex communication devices such as radar communication devices.

(Wen et al., 2019) [26] presented a BW-improved single-layer differential-fed MPA using two different resonant modes such as TM 30 and TM

50. In this present design, two long slots were placed symmetrically on predefined positions on the upper portion of the MPA with a peak electric field of TM 30 mode on the upper portion and the TM 50 on the null point. Due to the influence of capacitive reaction on the installed slots, they were reallocated to the TM 50 mode into an area of very low frequency when compared with the least affected TM 30 mode. This resulted in the formation of the BW with a wider operating range and with dual-resonant radiation. Because of the similar odd-order distribution of electromagnetic fields, both of the radiative patterns provide a similar amount of maximum radiation. The design of the antenna proposed in this work can be adopted on a single-layer dielectric substrate when compared to other multimode patch antennas. The prototype of the designed antenna was tested and results validate that this design possessed an improved of -10 dB bandwidth of 6.1% with a frequency range of 5.4-5.74 GHz and with 10.7 dBi of maximum realized gain. The improved efficiency of the presented design validates the potential and efficacy of the dual mode microstrip patch antenna.

(Ghannad et al., 2019) [27] proposed a design of MPAs with an aim of improving the isolation and matching for a two-element MPA array. In the present work, the design of two basic patch antennas was proposed wherein the antennas were arranged in a linear fashion and the isolation capacity and impedance equalization was enhanced without employing any traditional matching networks. The proposed design was a multifunctional design with the structure consisting of only two narrow T-shaped stubs which are connected to the feed lines. The design consisted of a narrow rectangular slab placed between the lines and a compact rectangular slot was placed on the ground plane. This arrangement offers a dense and simplified patch antenna with minimized cost and with a very low mutual coupling. The adaptability of the developed MPA was validated by fabricating a prototype of an antenna array which is very compact at a frequency of 5.5 GHz which is more appropriate for MIMO (multiple-input-multiple-output) systems. Both experimental and simulation outcomes were synchronized with an improvement of 16 dB, and 40 dB for matching and isolation respectively.

(Alibakhshikenari et al., 2019) [28] proposed a design with mutual coupling suppression observed between two MPAs employing an electromagnetic bandgap metamaterial fractal loading. The main aim of the proposed approach was to reduce the effect of mutual coupling between the two patches which are placed closely. The coupling was reduced by placing a fractal isolator between two radiating components. This approach reduced the distance between the radiator components to $\sim 0.65\lambda$ with the decrease in the mutual coupling of different frequency bands. Furthermore, it was also observed that using the presented approach, the two-element antenna was observed for operating over a wide range of frequencies. It was observed from the analysis that there was a steady elevation in the maximum gain which was about 71% with no effect in the radiation patterns. The functionalities of the antennas were substantiated by the simulation results and it was inferred that the proposed approach can effectively dwindle the mutual coupling between two patch antennas that are spaced closely in an array in the MIMO systems.

(Shao & Zhang, 2019) [29] proposed the fabrication process of a new and advanced differential shorted patch antenna (DSPA) was presented and the outcome of the same was compared with a normal single-ended SPA. It was observed from the evaluation that the proposed DSPA possessed relatively a compact and reduced dimension unlike the conventional SPA. In order to validate this, a prototype with a transmission line was proposed for demonstrating the narrowed resonant size of the DSPA. The reduction ratio of the sizes of the DSPA to the SPA was analysed and it was observed that the size reduction ratio was mainly dependent on the thickness of the dielectric substrate , shape of the antenna patcha and on the dielectric constant of the substrate. The reduction in the sizes of the DSPA and SPA was evaluated experimentally and it was observed that the resonant frequency of DSPA was increased with the decrease in the patch ratio which is contradictory in the case of SPA. Additionally, it was also inferred from the analysis that the DSPA showed superior directivity, more number of symmetrical radiation patterns, narrowed impedance bandwidth, and less cross-polarization radiation compared to SPA.

(Shen et al., 2019) [30] proposed a miniaturized two-element microstrip antenna array for a mm-wave band of 5G wireless communication systems. In the proposed research, the two MPAs that are differentiated by a narrow gap were fabricated on the surface of a electromagnetic bandgap structures (EBG) as the ground plane. The antennas were operated in 5G systems with a frequency range of 26 500-29 500 MHz. By applying the EBG ground, the two elements of the MPAs were closely placed with a wavelength of 0.3 measured from center to center. It was observed that the mutual coupling between the two antenna elements was able to attain a value which is more than 23 dB in the complete frequency bands whose value is more than 10 dB on a normal ground. Results show that the important radiation features of the two-element array were found to be in line with the EBG ground. It can be inferred from the results that this design approach is suitable for MIMO devices or at MM-wave bands for mobile communication systems.

3 Design of Microstrip patch antennas:

The superior characteristics and functionalities of MPAs have made them an attractive choice for various wireless communication devices. However, there are certain design challenges which need to be resolved to satisfy the wide bandwidth and multiple frequency requirements. Various mechanisms and technologies have been proposed for the design of MPAs to satisfy these requirements such as usage of different patch shapes, cutting slots, and implementation of different notches. There are some important design considerations which are prominently considered in the design of MPAs, such as: (Jain & Gupta, 2014) [31].

- Type of substrate required (based on application)
- Thickness of the dielectric substrate
- Patch shape and dimension
- Type of feeding techniques
- Resonant frequency

Among these design considerations, selection of an appropriate dielectric substrate is important which is selected based on the application, cost, size, and efficiency. Apart from this, another important aspect in the fabrication of MPA is the feeding technique.

3.1 Antenna design and configurations:

In the design and development of MPAs, initially the design parameters such as dielectric constant (ε_r), resonant frequency (f_o) and the height of the dielectric substrate (h) are determined. The width of the antenna for obtaining an effective radiation pattern and radiation efficiency is given as: (Bansal & Gupta, 2020) [32]

$$W = \frac{c}{2f_r}\sqrt{\left(\frac{2}{\varepsilon_r + 1}\right)} \quad \text{..... (2)}$$

Where, C is defined as the speed of the light. For evaluating the length of the patch on the substrate, it is essential to evaluate the effective dielectric constant of the substrate which is obtained as:

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[1 + \frac{12h}{W}\right]^{-\frac{1}{2}} \quad \text{..... (3)}$$

Using the above equation, the final length of the patch is measured using the below given expression:

$$L = \frac{1}{2f_r\sqrt{(\varepsilon_{reff})}\sqrt{(\mu_o\varepsilon_o)}} - 2\Delta L \quad \text{.... (4)}$$

Where $\triangle L$ is defined as an extension of the length of the patch; which is determined as: (Imran et al., 2018) [33]

$$\frac{\Delta L}{h} = 0.412\frac{(\varepsilon_{reff} + 0.3)\left(\frac{W}{h} + 0.264\right)}{(\varepsilon_{reff} - 0.258)\left(\frac{W}{h} + 0.8\right)} \quad \text{.... (5)}$$

Using the above given expressions, the dimension of the patch (length and width) can be determined.

3.2 Role of substrate in antenna design:

The initial stage in the fabrication of a MPA involves selection of an appropriate dielectric substrate material for fabrication. Various researchers have worked on different substrates and it was inferred that the substrates incorporated in MPA design ranges from $2.2 \le \varepsilon \le 12$. The size of the antenna depends on the permittivity of the dielectric substrate (alias Jeyanthi et al., 2013) [34]. Lower the value of permittivity, larger is the size of the antenna. However, with low permittivity, the antenna obtains larger bandwidth and provides better efficiency. The ε_r is controlled by the microwave circuit or radio frequency of the antenna. It must be observed that the potential and robustness of the antennas deteriorates with the adaption of a substrate with high dielectric constants. Air which possesses a minimal value of dielectric constant i.e., 1 yields a low return loss of -22.6449 whereas the Benzocyclobutane which has a dielectric constant of 2.6 provides a return loss of -18.1248 (Kumar et al., 2013) [35].

The theoretical evaluation and the influence of permittivity of the dielectric substrate is evaluated by determining the effective dielectric constant as shown in equation 3. The significance of substrate permittivity on resonant frequency is given as:

$$(f_r)_{110} = \frac{1.8412\nu_0}{2\pi a_e\sqrt{\varepsilon_r}} \quad .... (6)$$

The relation between the effective length and radius with substrate permittivity for a rectangular patch antenna is given as:

$$L_{eff} = \frac{c}{2f_o\sqrt{\varepsilon_{reff}}} \quad .... (7)$$

Similarly, the relation between the effective length and effective radius with substrate permittivity for a circular patch antenna is given as:

$$a_e = a\left\{1 + \frac{2h}{\pi\varepsilon_r a}\left[\ln\left(\frac{\pi a}{2h}\right) + 1.7726\right]\right\}^{1/2} \quad .... (8)$$

The comparison of different substrates on antenna parameters are tabulated in table 2.

Table 2. Comparative analysis of different substrates of antenna parameters

Substrates	**Dielectric constant (ε_r)**	**Loss Tangent**	**Resonance frequency**	**Return Loss**	**Gain**
RT-Duroid	2.2	0.0009	10 GHz	-	12.03
Duroid 6010	10.7	0.0060	2.455	-9.449	4.02
Benzocyclobutane	2.6	0	2.04 GHz	-18.124	5.5
Fr-4	4.4	0.018	5.8 GHz	-14.73	9.8
Roger 4350	3.48	0.004	2.586 GHz	-25.29	4.62
Nylon fabric	3.6	0.0083	989 MHz	-35.42	6.11
Foam	1.05	0	454 MHz	-16.732	2.73

The effect of different dielectric substrates on size, bandwidth and efficiency of MPAs are illustrated in Table 3.

Table 3. Effect of various substrates on antenna parameters

Substrates	**Size Reduction**	**Bandwidth**	**Efficiency**
RT-Duroid	Moderate	Moderate	88.64
Nylon fabric	Moderate	Moderate	-
Fr-4	Moderate	Moderate	99.60
Benzocyclobutane	Moderate	Moderate	96.51
Foam	High	Moderate	61

Roger 4350	Moderate	Moderate	99.66
Duroid 6010	Low	Minimum	93.51

3.3 Feeding techniques for microstrip patch antennas:

The feeding processes essays a prominent and significant role in the development and implementation of MPAs. The feedline in antenna design is used for exciting and radiating the antenna through direct or indirect contact. In contact mode, the RF signal is directly fed into the radiation patch using any connecting component such as microstrip line. Whereas in non-contact mode or indirect contact mode, the electromagnetic field coupling is used to transfer the power between the radiating patches and between the microstrip line: example using aperture and proximity feeding techniques.

There are multiple feeding processes that are used in design of MPAs such as coaxial probe feed, microstrip line, aperture coupling and proximity coupling (Garg et al., 2001) [36] (Singh & Tripathi, 2011) [37] (Nandlal et al., 2019) [38].

3.3.1 Coaxial probe feeding technique:

In this feeding mechanism the conductor present inside the coaxial is associated with the radiation patch of the antenna and the conductor mounted on the outer part of the coaxial is fixed to the ground plane (Arora et al., 2015) [39]. The schematic of the coaxial probe is illustrated in figure 3.1

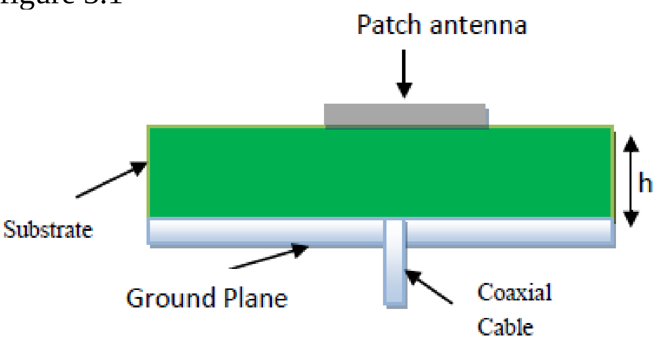

Figure 3.1 Illustration of the coaxial probe feed

Coaxial feeding is simple to fabricate, easier to match with very minimal spurious radiation. Narrow bandwidth is one of the prominent limitations and it is challenging to design this feed especially for the substrates with high thickness.

3.3.2 Microstrip line feed:

It is the most simpler and easiest technique to fabricate since it just involves a conducting strip which is connected to the patch and hence is regarded as an extension of the patch. The microstrip line is modelled easily and can be matched by handling the inset position. One of the prominent limitations of this process is the rise in the spurious radiation due to the expansion of the substrate thickness which results in the narrow bandwidth (Bisht et al., 2014) [40]. An illustration of the microstrip line feed is presented in figure 3.2

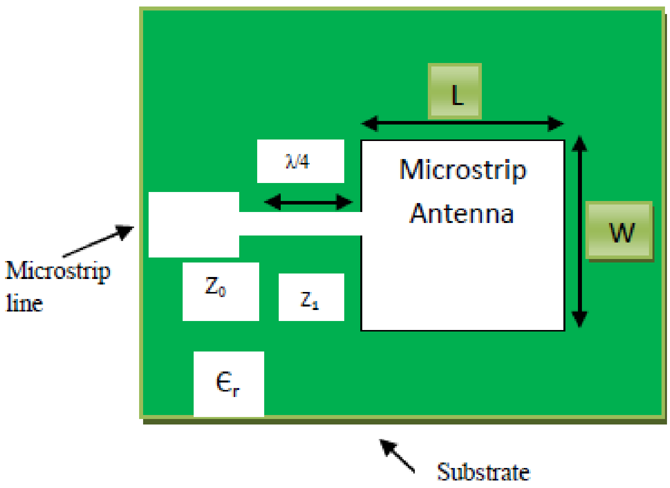

Figure 3.2 Microstrip line feed patch antenna

3.3.3 Aperture coupled feed patch antenna:

The aperture coupled feed technique involves fabrication of two different substrates which are distinguished by the ground plane as presented in figure 3.3. The lower substrate which is located on the bottom side consists of a microstrip feed line and there is mutual coupling between the energy of the feedline and the antenna through a slot which separates the two substrates (Jothilakshmi et al., 2019) [41]. This design will enable the effective optimization of the feeding process and the radiating element which is most advantageous.

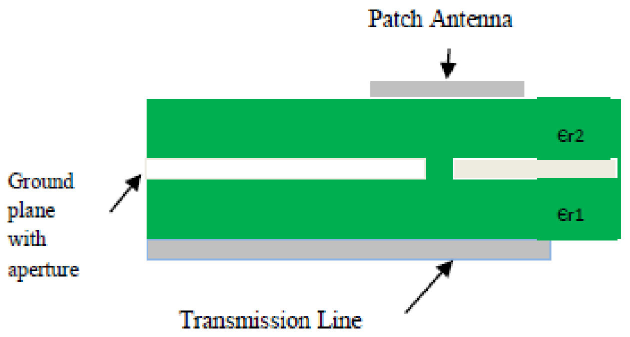

Figure 3.3 Aperture coupled feed patch antenna

3.3.4 Proximity coupling feed patch antenna:

This technique possesses higher bandwidth and lower spurious radiation (Sowjanya et al., 2019) [42]. But this technique involves a lot of complexities in the fabrication process. The coupling process in this technique is capacitive in nature and the impedance matching in this process is controlled by calibrating the length of the feed and the ratio of width-to-length of the patch (Anand & Palniladevi, 2020) [43]. The schematic representation of the proximity coupling feed is illustrated in figure 3.4.

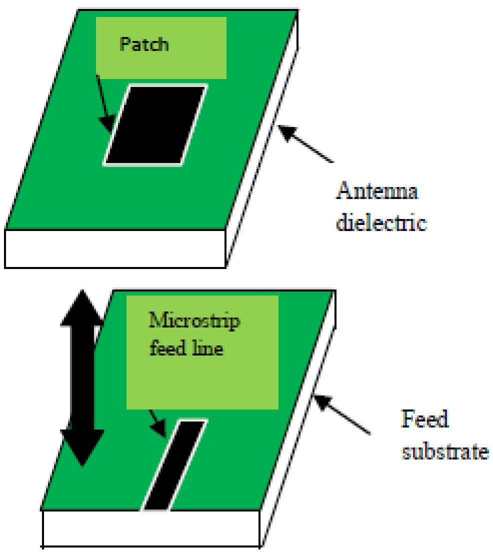

Figure 3.4 Illustration of Proximity coupled MPA

One of the prominent limitations of this process is the complexity associated with fabrication of the antenna. It is challenging to construct two dielectric layers which require an exact and appropriate alignment.

4. Comparative Analysis:

This section discusses various comparative analysis related to microstrip patch antennas:

Table 4 Comparative analysis of functionalities of various MPAs

Functionalities	**MPA**	**Microstrip slot antenna**	**Printed Dipole antenna**
Dual-Frequency Operation	Achievable	Achievable	Achievable
Fabrication	Highly feasible	Feasible	Feasible
Spurious radiation	Exists	Exists	Exists
Profile	Thin and Narrow	Thin and Narrow	Thin and Narrow
Bandwidth	2 - 50%	5 -30%	-30%
Shape Flexibility	Any shape	Mostly rectangular and circular shapes	Rectangular and triangular
Polarization	Both linear and circular	Both linear and circular	Linear

The comparative analysis of the different feeding techniques are illustrated in table 5

Table 5. Comparative analysis of various feeding techniques

Functionalities	**Microstrip line feed**	**Coaxial feed**	**Aperture coupled feed**	**Proximity coupled feed**
Spurious feed radiation	High	High	Low	Minimum
Reliability	Moderate	Low (because of soldering effect)	Average	Average
Complexity of fabrication	Low	Soldering and drilling needed	Alignment required	Alignment required
Impedance matching	Good	Good	Good	Good
Return Loss	Low	High	Low	High
Resonant Frequency	High	Low	Poor	Highest
Polarization Purity	Poor	Poor	Poor	Excellent
Bandwidth	2 - 5%	2-5 %	21%	13%

The schematic representation of the comparative analysis for different feeding techniques is presented in figures 4.1 4.2, and 4.3

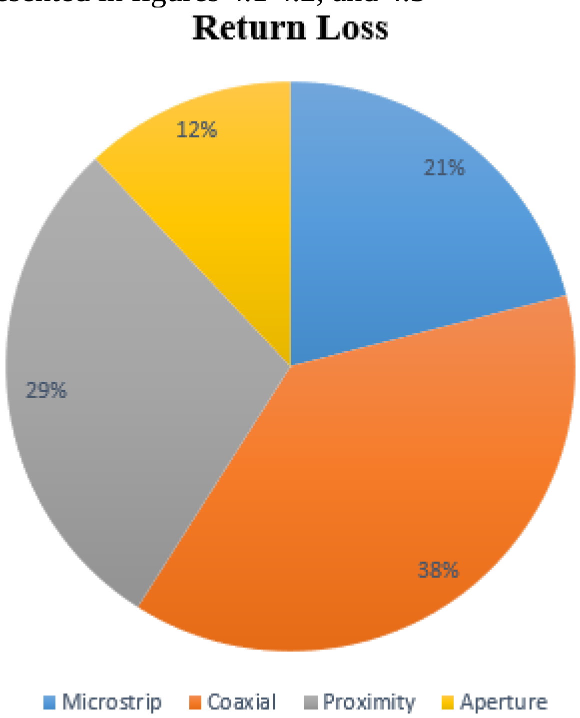

Figure 4.1 Return loss of different feeding technologies

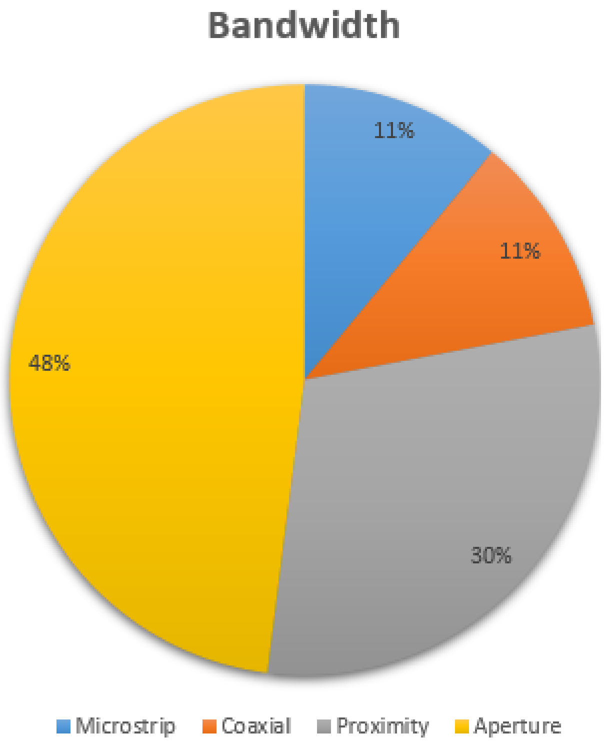

Figure 4.2 Bandwidth analysis of different feeding processes

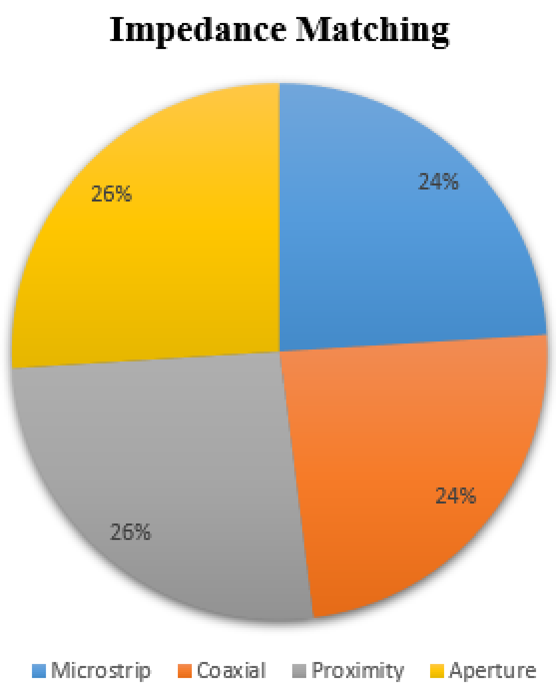

Figure 4.3 Analysis of Impedance matching for different feeding mechanisms

5. Conclusion:

This research provides a comprehensive analysis of design of microstrip patch antennas. The review analysis consists of a brief overview of MPAs, its design considerations and analysis of multiple feeding mechanisms. Microstrip patch antennas have gained vast significance in the field of wireless communication because of its superior characteristics such as reduced size, stability towards multiple frequency bands, low cost, and simple fabrication. A comparative analysis is presented which includes analysis and collation of different feeding techniques and effect of different characteristics on microstrip antennas. Some of the prominent observations inferred from the analysis are:

- The selection of appropriate dielectric substrate is one of the prominent constraints in the design of MPAs.
- The Conductor and dielectric losses increase with the decrease in the substrate thickness.
- An appropriate substrate is selected based on the application, cost, size, and efficiency.
- Feeding techniques in antenna design influences the return loss, bandwidth, and impedance matching.
- The maximum bandwidth can be obtained by employing aperture coupling feeding technique and the better radiation efficiency and impedance matching can be achieved using proximity coupling.
- Coaxial feeding method provides narrow bandwidth and the high return loss is obtained at the resonant frequency.

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