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Abstract

Microstrip Patch Antenna (MPA) is an antenna that is made of a metal foil which is printed on the face of a Printed Circuit Board (PCB) which on the other face has a ground plane also made of metal foil. It has become popular basically because of its many benefits over other types of antennas, which includes; cheap in price, not heavy, planar configuration, ease of conformity, low profile, ease of fabrication among others despite her limitations which include low efficiency, lower gain and higher level of cross polarization. In almost all wireless communication, the microstrip patch antenna has replaced all other type of antennas as a result of its peculiarity which has made its use of preference to others. The microstrip patch could be of various types of shapes which are also an advantage. Varying techniques have been employ in the making of the rectangular microstrip patch antenna in other to achieve improvement in the performance of the antenna amongst which are: stubs introduction, use of different types of material for plating, shape varying, defect and deformation introduction and introduction of slots. The introduction of the various techniques is aim at improving performance in different area, such as gain, bandwidth, radiation pattern and characteristics. This review looks at the rectangular microstrip patch antenna and the various advantages in its usage for wideband applications.

*Keywords: Microstrip patch antenna, Rectangular patch, Wideband applications, Substrates*

# Introduction

The most fundamental part of any wireless electrical connection is an antenna. It links the free space, transmitter or free space, and recipients [1]–[4]. It is a gadget for the transmission and reception of electromagnetic waves. They are mostly resounding gadgets, whose operation is efficient only over a fairly limited frequency band. The frequency of the antenna must be in consonance with that of the connected radio system for it to be operational; otherwise, reception and transmission will be impaired [1],[5]. After the Printed Circuit Board (PCB) was introduced, the antenna that became popular is the MPA. Usually, MPAs are fabricated using Printed Circuit Board (PCB) techniques [5]–[7]. Their use is usually at microwave frequencies (above 1 GHz). A MPA is made of a patch (patch antenna) that is attached to the surface of a PCB and ground on the other side. This patch could be made of different shapes and both the patch and ground are from metal foil. In 1970, a group of researchers and Robert E. Munson using a low loss substrate developed practically the MPA. Earlier, G. A. Deschamps had initially proposed it in 1953, while Guitton and Bassinot patented a design in 1955 [3],[7],[8]. Since the introduction of MPAs, they have turn out to be the most common type of antenna and within the last two decades the most rapidly developing antenna field [9]. They have witnessed extensive range of applications as a result of their scores of upper hand like: lightweight, inconspicuous, affordable, level arrangement, ability to conform easily, unrivalled compactness, fit for an array with no difficulty in production and incorporation with Microwave Monolithic Integrated Circuits (MMICs). MPAs have been greatly utilized for both civil and military applications which includes Radio-Frequency Identification (RFID), broadcast radio, mobile systems, Global Positioning System (GPS), television, Multiple-Input Multiple-Output (MIMO) systems, vehicle collision avoidance system, satellite communications, surveillance systems, direction founding, radar systems, remote sensing, and missile guidance [10]–[13], thus evolving from an academic novelty to commercial reality [9].

# Methodology

A MPA is an antenna that is made up of a patch on a PCB and a ground plane on the reverse side, the patch and ground plane are made of metal foil. Simply put, a MPA is a portable layered antenna. Fig. 1 is the arrangement of MPA



Fig. 1 Arrangement of MPA [10]

 Various shapes are adopted for the fabrication of the patch. Some of the popularly adopted shapes are shown in Fig 2.



Fig. 2 Some Shapes of the Patch [14]

Rectangular and circular microstrip antennas are mainly used because of no difficulty in analyzing the fabrication and fair radiation attributes, especially moderate cross-polarization and ability to operate over several frequencies [14]–[16].

 Radiation in microstrip patch antenna primarily occur at the border of the patch and the ground plane as a result of the fields of the fringes. The radiation rises as the frequency increases, increase in the thickness of the substrate, low valued permittivity, begins mainly at discontinuations [17]–[20].

Table 1 Specification of Various Substrate Materials

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Material** | **Dielectric Constant ɛr** | **Mass Density kg/m3** | **Dielectric loss Tangent** | **Relative Permeability** |
| **FR4 Epoxy** | 4.4 | 1900 | 0.02 | 1 |
| **Modified Epoxy** | 4.4 | 0 | 0.02 | 1 |
| **Polyamide** | 4.2 | 0 | 0.004 | 1 |
| **Arlon AD430™** | 4.3 | 0 | 0.003 | 1 |
| **Polyimide Quartz** | 4 | 0 | 0 | 1 |

Source: [21],[22]

2.1. Feeding Techniques of Microstrip Patch Antenna

Four basic techniques are engaged in the feeding of microstrip patch antennas. Each of these techniques is unique on its own. Table 2 is the analogy of the feeding techniques.

Table 2: Analogy of Techniques of Feeding Microstrips

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Attribute**  | **Microstrip Line Feed** | **Coaxial Feed** | **Aperture Coupled Feed** | **Proximity Coupled Feed** |
| **Radiation of Feed** | Better  | Better  | Reduced  | Minimal |
| **Reliability** | Better  | Fine | Fine | Fine  |
| **Ease of Fabrication** | Uncomplicated | Requires soldering and drilling  | Requires to be aligned | Requires to be aligned |
| **Impedance Matching** | Uncomplicated | Uncomplicated | Uncomplicated | Uncomplicated |
| **Bandwidth** | 2-5% | 2-5% | 21% | 13% |

[23]–[24]

Three modes of analysis are engaged for MPA: transmission line, cavity and full-wave. Table 3 is the analogy of the three modes of analysis.

Table 3: Analogy of Microstrip Patch Antenna Mode of Analysis

|  |  |  |  |
| --- | --- | --- | --- |
| **Characteristics**  | **Transmission line** | **Cavity mode** | **Full-wave** |
| **Insight** **Accuracy**  | * Good physical insight
* less accurate
 | * Quite complex
* Good physical insight
* More accurate
 | * Most accurate in the design of finite and infinite arrays of stacked structures
 |

[20],[25]

# Results and Discussion

Ability to be used with thin substrates and ease in analyzing has made the rectangular patch the most widely used patch [1].

In designing the rectangular patch antenna, resonant frequency and substrate material to be used must first be determined. For provision of better efficiencies, wider bandwidth and greater radiation in wideband frequency, a broad substrate with a dielectric constant that is little is favoured.

The patch width and length will be calculated using equations (1) and (2):

 (1)

and

 (2)

For the calculation, effective dielectric constant (ɛreff) and extension in length (ΔL) in (2) must be calculated using;

 (3)

and

 (4)

 (5)

Where:

W stands for patch width,

C stands for velocity of light,

fr stands for resonant frequency,

ɛr stands for dielectric constant of the substrate,

L stands for patch length,

ɛreff stands for effective dielectric constant,

µo stands for permeability of free space,

ɛo stands for permittivity of free space,

ΔL stands for extension of patch length,

h stands for thickness of the dielectric substrate,

Leff stands for effective patch length.

Rectangular MPA has been an area of interest due to its affordability, little interference of the radiation with humans, better mechanical reliability and maintenance of very good performance over a wide range of frequency [26],[27]. Reference [28] designed and simulated a rectangular strip for wideband applications which is able to operate between 1.91 – 6.19 GHz. This antenna achieved a bandwidth of 105.7% with 5 slots and 4 resonant frequencies without external circuitry while the work of references [29]–[30] proposed the use of Rogers 4350 for the printing of their antenna. It has a trident shaped interface as its feed for enhancing the bandwidth. Reference [31] proposed an antenna that has a length more significant than the width. A stub that is rectangular is attached for improvement of the impedance matching and increases its radiation. It operates at 2GHz to 11.05GHz frequency and has good bandwidth but not adequate for use for long range radio communication because of interference and limitation in the power that is transmitted.

Reference [32] proposed an antenna with a conical radiation pattern. The antenna achieved a high gain of 8dB with the aid of an antenna that is truncated along its width and a broadband response obtained through 4 patches of sector shape which are coupled through the gaps which has the truncated edges on the other side. Reference [33] proposed an antenna with twin boomerang form slots and another pair of notches which are symmetrical when viewed through the y-axis. The outcome of the simulation showed a radiation pattern which in the direction of the radiation has a broadside pattern and within the operating band there exist lobes that are small in size.

Table $. Current State of Work in Microstrip Patch Antenna

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Author** | **Year** | **Frequency** | **Antenna Proposed** | **Technology used** | **Advantage**  |
| **[15]** | 2018 | 2.4 GHz | Designed and fabricated an antenna for a single S-band frequency | ADS software applicable in GSM850, GSM900, DCS, PCS, UMTS, WWAN | The antenna was found to operate flawlessly |
| **[29] and [30]**  | 2010 and 2018 | 0.82 GHz-25 GHz  | Designed an antenna for print on a 3.48 Rogers 4350 | Use of trident shaped feed interface | Better enhancement of bandwidth |
| **[34]** | 2010 | 5.75 GHz, 13.5 GHz & 19.4 GHz | An antenna that operate on different frequency and polarization a one layer structure | Operation of antenna at three sub-bands | Its simulated results show that it offers excellent performance for ultra-wideband applications |
| **[31]** | 2019 | 2 GHz-11GHz | It has a length more significant than the width | A stub that is rectangular is attached for improvement of the impedance matching and increase its radiation | It has good bandwidth but interferes with other radio-based technologies |
| **[35]** | 2015 | 2.4 GHz | Fabricated the antenna with different platings for GSM band |  | Gold nearest to the desired result but antenna size is large |
| **[36]** | 2019 |  | Artificial intelligence driven method is used for the design | A radiator that is circular is etched with rectangular slot | Bandwidth is maintained when placed near a human phantom |
| **[37]** | 2018 |  | Designed an antenna that used a low-cost and readily available glass epoxy FR-4 substrate |  | Obtained simulated and measured results in good agreement while utilizes modified circular strip for wideband application and the design achieved a stable ultra-wideband over the frequency range for WiMAX application |
| **[38]** | 2003 | 4.95 GHz | Excitation of nodes on different plane by using unequal arms U shaped slots on patches for wideband wireless | 3D full wave EM simulator is used in designing the antenna | Good for wireless communication applications |
| **[28]** | 2018 | 2.166 GHz-4.245 GHz | A compact modified star shaped microstrip patch antenna | HFSS software is used for simulation | The results that were arrived at after the simulation and measurement are in consonance. In addition, power reflected back from the antenna is less. |
| **[39]** | 2016 | 2.45-10.9 GHz | A slot in cup shaped and ground in L shape on patch of rectangle shape | HFSS and Agilent N5230A vector network analyser | All sampling frequencies has almost omnidirectional radiating patterns |
| **[40]** | 2018 | 1.5-2.8 GHz | Double wideband monopole antenna for several wireless applications is proposed | Different parameters of the antenna were varied  | Large bandwidth and high gain |
| **[41]** | 2009 | 3 GHz | A pair of parasitic and rectangular fed patches |  | Bandwidth and gain improvement |
| **[42]** | 2013 | 3.0583-10.8333 GHz | U and T shaped notch made up of a pair of bevels as its corner | CST used for design and simulation | Improved return loss |
| **[43]** | 2011 | 2.9-11.3 GHz | Structure was optimized using multi-stepped deformation | CST MWS (CST microwave studio) | Good radiation characteristic |
| **[44]** | 2015 | 2.5-11.21 GHz | Small size UWB MPA | Design, simulation and optimization done using HFSS and CST | Required standard met |
| **[33]** | 2017 | 2.43-9.54 GHz | Two slots in boomerang shape and a pair of notches symmetric around y axis and in the ground plane two of a kind U slots for bandwidth augmentation | Designed using Ansys HFSS | Can be used for various applications within the frequency range |
| **[45]** | 2019 | 3.5-15 GHz | Rectangular patch with slots and a patch which is arranged in order on a small ground plane | Simulation is carried out on CST and HFSS | Good bandwidth and directional radiation pattern on larger portion of the band of operation |
| **[27]** | 2019 |  | Monopole ultra-wideband (UWB) patch that enhances bandwidth (BW) performance for super-wideband applications | Modified patch is fastened to a FR-4 epoxy substrate and a microstrip type transmission line feed | Improved gain and directivity |
| **[46]** | 2018 | 3.8-14.8 GHz | A rectangular patch and a truncated ground plane | Rogers substrate used for the proposed antenna because it is easy to fabricate and it is cheap | Measured and simulated results agree and the pattern of radiation is good |
| **[47]** | 2012 | 1.9-3.6 GHz | Design and analysis of a Double rectangular ring microstrip antenna which is suitable for wireless application but with Defected Ground Structure (DGS) | Design done with CST 2009 | Improved bandwidth, radiation pattrn and beamwidth |
| **[48]** | 2016 | 3-10GHz | Design is rectangular patch with inverted L shaped strip on rectangular groung plane |  | Antenna volume greatly reduced  |
| **[49]** | 2017 | 793.66 MHz up to 2501.34 MHz |  | Substrate used is FR-4 and simulation done on CST | Gain increases with increasing operating frequency |
| **[50]** | 2018 | 0.94-1.9 GHz | Shape of patch is rectangular and has same shaped slot on its top | FR4 substrate, copper for conduction layer and simulation carried out on CST 2014 | Antenna performance is acceptable |
| **[51]** | 2017 | 1.8-10.8 GHz | Borosilicate was used for the antenna design | Simulation done on CST | Fairly omnidirectional behavior |
| **[52]** | 2016 | 3.8-15.2 GHz | Diagonal cuts which are aided with circular edges were introduced on the patch and partial ground | Simulation and analysis done on HFSS  | Modifications were used to improve the bandwidth |
| **[53]** | 2014 | 4.1-14.6 GHz | Design is irregular shaped slots and partial ground | Simulation done on HFSS | Could be used for varieties of applications |
| **[54]** | 2018 | 3.1-7.5 GHz | Rectangular and semi-circle slots and partial ground | FR4 and simulation is done using CST | Could be used in varieties of wireless applications that required improved parameters |
| **[55]** | 2019 | 3.3 GHz to more than 35 GHz | Microstrip-fed printed monopole antenna is designed | Simulation is done using CST | Improvement in compactness of antenna |
| **[56]** | 2020 | 26.88-61.17 GHz | Design is an array of rectangular shape on modified plane which could be used for MIMO applications | Rogers RT/Duroid 5880 substrate |  |
| **[57]** | 2011 | 2.9-13.3 GHz | Design is a monopole which is fed by microstrip line |  | Improvement in size minimization and bandwidth |
| **[58]** | 2014 | 3.04 to over 10.87 GHz | Design is slot of rectangular shape at the back but the patch shape is inverted T | Ansoft HFSS | Simple configuration and easy to fabricate |
| **[59]** | 2018 | 2.53-2.71 GHz | Design is S band RMPA | CAD FEKO used for simulation | Good agreements between simulated and measured results |
| **[60]** | 2017 | 3.1-10.6 GHz | Design is made of introduction of slots into the ground and patch of a rectangular patch and the patch is fed by a microstrip line | FR4 and HFSS | More current controllability |
| **[61]** | 2019 | 2-2.49 GHz | Slotted patch rectangular microstrip patch antenna | Glass (pyrex) (lossy) substrate and simulated using CST 2017 | A good candidate for ISM band applications |
| **[62]** | 2015 | 960-2400 MHz | Design is a parasitic patch that is fed by wideband capacitance | FR4 substrates and simulation carried out on HFSS | Increased bandwidth |
| **[63]** | 2010 | 3.6-15 GHz | Design is made up of a substrate with patch with slot of U shape and finite ground plane on either side | Optimization and design is on extensive 3D EM | Bandwidth and size are improved  |
| **[64] & [65]** | 2015 | 4.3127-5.537 GHz | Design is CPW fed slotted rectangular MPA | CST 2012 is used for simulation | Very good for use in wireless applications within the wideband range |
| **[66]** | 2021 | 2.4 GHz | Design is introduction of layers and diagonal slots on rectangular MPA | Simulation is done using HFSS 13 | Minimum power reflection achieved with the diagonally coupled MPA |
| **[67]** | 2020 | 3.1636–3.2681 GHz | Design is rectangular MPA which is Inset fed | Simulation done using AWR simulator | Minimum return loss and VSWR achieved |
| **[68]** | 2022 | 3.3-3.8 GHz | Design radiating element with notches fed by microstrip line | CST microwave studio suite used for simulation | Ability to insert CSRR cells on MPA |
| **[69]** | 2021 | 5.2 GHz | Design is a 3 x 3 array  | Simulation done using CST | High gain and low complexity |
| **[70]** | 2021 | 8.45 GHz | Design uses coupled microstrip patches | Agilent network analyzer E5071C | Compact size, good radiation characteristics and low cross polarization |

# Conclusion

This review has shown that the rectangular MPA has enjoyed good research interest of researchers and the following were observed from the various works:

1. Introduction of stubs increases bandwidth.
2. Varying the shape of the patch enhances bandwidth.
3. Use of gold for plating gives a very good reflection.
4. Use of unequal arm length aid in the performance of the antenna.
5. Introduction of cup shaped slot and L shaped ground assist in obtaining nearly omnidirectional radiation pattern.
6. Multistepped deformation gives good radiation characteristics.
7. Truncated and defected ground structure assist in radiation pattern.
8. Slots and varying shape of patch improves antenna performance.

It should be noted that improvement need to be put in the study of the rectangular MPA so that a design could enjoy majority of the many observed gains that various designs enjoyed.

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