A review on miniaturization techniques for microstrip patch antenna

Amit A. Rakholiya[1], Namrata V. Langhnoja[2]

[1] P.G. Student, Communication system Engineering Department, LDCE, Gujarat, India
[2] Assistant Professor, Communication system Engineering Department, LDCE, Gujarat, India

ABSTRACT

Microstrip patch antenna (MPA) has become an integral part of wireless communication system because of their advantages such as low profile, light weight, available with planner and non-planner structure. The increasing growth of wireless system requires miniaturized antenna. Conventional antenna size is about half wavelength. With the development of the technologies wireless systems becoming more and more compact so antenna size must have been reduced. This study shows some of the techniques to reduce size of microstrip patch antenna. This miniaturization techniques include use of high permittivity ϵ_r materials, use of meta- materials, Sierpinski carpet fractal method, using pins between patch and ground plane, introducing slots in the patch. The major features and drawbacks of these methods are highlighted in this study.

Keyword : *Miniaturization, Microstrip patch antenna*

1. INTRODUCTION

Wireless systems are present everywhere and also use of wireless systems is increasing rapidly. These systems include AM and FM radios, Global Positioning Systems (GPS), RFID etc. performances of these devices are defined by the characteristics of the antennas used. So that the designing of antenna is most important part for designing any wireless system. Nowadays printed antennas are most popular for compact electronics and wireless systems designing because of their low profile nature and ease of integration. Most commonly used printed antennas are microstrip patch antennas (MPA).

Although most of the parts of communication systems have seen considerable reduction in size by using fabrication technology. Still size reduction of the antennas is very difficult task. A conventional antennas have dimensions of half wavelength of the operating frequency. Antenna performance is very important part to be considered while reducing the size of antenna. Number of study published on the topic of antenna performances. All theories concluded that size reduction can be achieved on the expense of the antenna bandwidth and gain. These [1] theories shows the limit of Q-factor on the antenna performances. Nowadays design of electrically small antennas are interest of many research groups and many novel antenna structure has appeared in the miniaturized form. These include microstrip patch, slot antennas and others.

The microstrip patch antenna is planar printed antenna, which is well known and its theory of operation is well developed. All of the major and novel methods for miniature the antenna is discussed and surveyed in this review paper. This papers includes basic information and methods for miniature antenna for students and professionals.

This paper organized as follow. The basics of patch antennas is described in the section II. The main approach for miniaturization of antenna is discussed in section III. A summary of different miniaturization methods and effects of that is discussed in section IV. Conclusion is presented in section V.

2. MICROSTRIP PATCH

Microstrip patch antennas can be designed by placing conductor material on both side of the dielectric substrate material. One side of the substrate will be radiating patch and other side conductor will be ground plane of the patch antenna.[2] Also this patch of antenna can be rectangular, circular or any other shaped. Rectangular and circularly shaped patch is widely used since its design is simple and easy to fabrication. MPAs have several advantages like easy to fabricate because of its simple design, it can be fabricated on any cheap substrate material, easy to under the operation of the microstip patch antenna, substrate materials are easily available so cost effective, because of its low profile it can be used with any other circuits in various applications such as GPS receivers, mobile phones, any communication systems etc.

Microstrip patch antenna can be analysed by transmission line model. This model represents the Microstrip antenna by two slots of width W and height h, separated by a transmission line of length L. The Microstrip is essentially non-homogeneous line of two dielectrics, typically the substrate and air. [2]

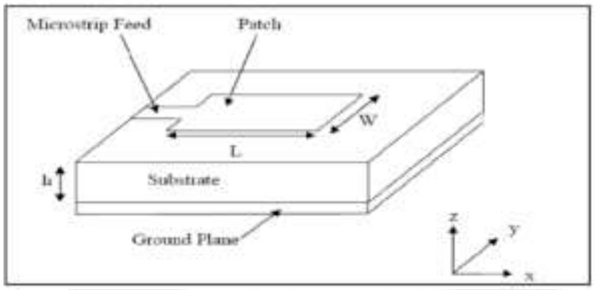

Fig. 1. Microstrip patch antenna

Most of the electric field lines reside in the substrate and parts of some lines in air. As a result, this transmission line cannot support pure transverse electric-magnetic (TEM) mode of transmission, since the phase velocities would be different in the air and the substrate. Instead, the dominant mode of propagation would be the quasi-TEM mode. Hence, an effective dielectric constant (ϵ_{reff}) must be obtained in order to account for the fringing and the wave propagation in the line. The value of ϵ_{reff} is slightly less than ϵ_r because the fringing fields around the periphery of the patch are not confined in the dielectric substrate but are also spread in the air. The expression for ϵ_{reff} is given as:

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[1 + 12\left(\frac{h}{W}\right)\right]^{-0.5}$$

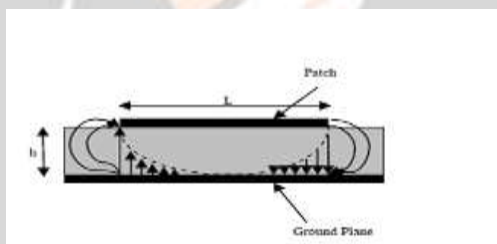

Fig. 2. Fringing fields

In order to operate in the fundamental TM_{10} mode, the length of the patch must be slightly less than $\lambda / 2$ where λ is the wavelength in the dielectric medium and is equal to 0 where λ_0 is the free space wavelength. The TM_{10} mode implies that the field varies one $\lambda / 2$ cycles along the length, and there is no variation along the width of the patch. The Microstrip patch antenna is represented by two slots, separated by a transmission line of length L and open circuited at both the ends. Along the width of the patch, the voltage is maximum and current is minimum due to the open ends. The fields at the edges can be resolved into normal and tangential components with respect to the ground plane. It is seen that the normal components of the electric field at the two edges along the width are in opposite directions and thus out of phase since the patch is $\lambda / 2$ long and hence they cancel each other in the broadside direction. The tangential components, which are in phase, means that the resulting fields combine to give maximum radiated field normal to the surface of the structure. Hence the edges along the width can be represented as two radiating slots, which are $\lambda / 2$ apart and excited in phase and radiating in the half space above the ground plane. The fringing fields along the width can be modelled as radiating slots and electrically the patch of the Microstrip antenna looks greater than its physical dimensions. [3]

Full wave methods are also used to determine the design parameter these methods uses computer-intensive numerical methods such as finite difference time domain, finite element method or method of moment also they provide little physical inside. HFSS™, FEKO™, CST, IEEA™ are available for solving full wave methods.

MPAs can be analysed using cavity model also. A MPAs can be considered as cavity filled with a dielectric substrate with non-PEC (perfect electrical conductor) and because of the leakages of cavity walls radiation takes place. For analysis fields inside the cavity will be solved first, here top and bottom part of cavity is considered as

PECs and sides are assumed to be a perfect magnetic conductors. Now these field distribution can be found by applying boundary conditions and resonant frequency and characteristic performances can be found.
Although both of these methods are easy to be implement. There are different methods for feeding the patch antenna such as transmission line, coaxial cable feeding, aperture coupled feed, proximity coupled method. However they lead to complex designs.

3. MINIATURIZATION OF PATCH ANTENNA

Miniaturization of an antenna is topic of interest for a long time. Most of the study concluded that reducing the size of antenna gain and bandwidth also reduce by some fraction. It has been well known that there is a theoretical lower limit on Q factor that can be achieved for antenna.[1] Theoretical lower bound of Q-factor can be given by

$$Q = \frac{1}{ka} + \frac{1}{(ka)^3}$$

Where 'k' is wave number and given expression is valid for lossless antenna. It shows that by decreasing the size of antenna Q factor increases so antenna performances reduces. So Q can be reduce at the expense of the antenna efficiency and gain of antenna.
Basically there are two methods to miniaturize microstrip patch antenna. The first method is to change the properties of substrate such that effective wavelength in the substrate is reduced. The second method is to increase the electrical path for current flowing.

3.1 Use of High permittivity material

The easiest way to reduce the size of patch antenna is to use high dielectric constant (ϵ_r) material. Antenna dimensions such as length and width are inversely proportional to the square root of relative permittivity of the substrate material. By using higher dielectric constant materials surface wave propagation will increase within the substrate and results in lower radiation efficiency because of increased losses and also bandwidth will decrease. Size reduction in the ground plane results poor polarization as well as changes the performance characteristics of patch antenna [4].
Various studies have investigated different materials as well as configurations to effectively use the above approach to miniaturise an MPA. Microstrip patch antennas with thicker substrate and dielectric constant of 10 to 13 were analysed [5]. Radiation performances were found different from that of conventional antennas. Input impedances were less than its theoretical values for thin substrates. Ceramic substrate is also used by some groups to reduce the size of antennas. There are various types of ceramic substrate available. A square ring microstrip patch antenna was developed on the ceramic substrate of dielectric constant of 58. [6] Circular polarization was achieved by simple microstrip feed line through coupling on the same plane. Size reduction was achieved by 50 % with respect to conventional antenna for FR4 substrate. Impedance bandwidth of 1.1% achieved at 1573 MHz frequency. Magneto-dielectric substrate was also used for miniaturization of microstrip patch antenna. By using this method 65% size reduction was achieved at 2.45 GHz with respect to conventional antenna [8].

3.2 Use of sierpinski carpet fractal method

The space-filling property of the fractal causes effectively increase the electrical length which is used to reduce the size of the antenna. Sierpinski carpet fractal method with different iterations was used to reduce the size of the patch of the microstrip patch antenna. By using this method 32 % size reduction was achieved at 2^{nd} iteration. In this design initially patch was divided into nine congruent rectangles and central rectangle was removed. In the further iterations remaining eight rectangle were again divided into another nine congruent rectangles and from these rectangles again central rectangle was removed. This similar procedure was followed for other iterations. This design was not printed for the whole part of design. The part containing feed line was not disturbed by the Sierpinski carpet fractal to get better impedance matching.
The iterative process was based on the following rules:

$$N_n = 8^n$$

$$L_n = \left(\frac{1}{3}\right)^n$$

$$A_n = \left(\frac{8}{9}\right)^n$$

Where N_n is the number of rectangles covering the radiating material, L_n is the length ratio, A_n is the ratio for fractal area.
32% of size reduction was achieved with the same antenna performance at second iteration at 2.45 GHz operating frequency. [7] Return loss, impedance matching and antenna gain results were compared with conventional base antenna.

3.3 Use of shorting pins between patch and ground plane

By using the shorting pins between the patch and ground plane size reduction of antenna can be achieved because it makes antenna electrically small. With respect to transmission line model, for a half wavelength rectangular patch antenna E-field distribution is maximum at the radiating edges and zero at the middle. So we can remove the one half of that distribution and also can get the same Q performance at the same resonant frequency that is called quarter wavelength antenna. By introducing shorting pins between patch and ground plane higher size reduction achieved but directivity was reduced and hence antenna gain was also reduced.

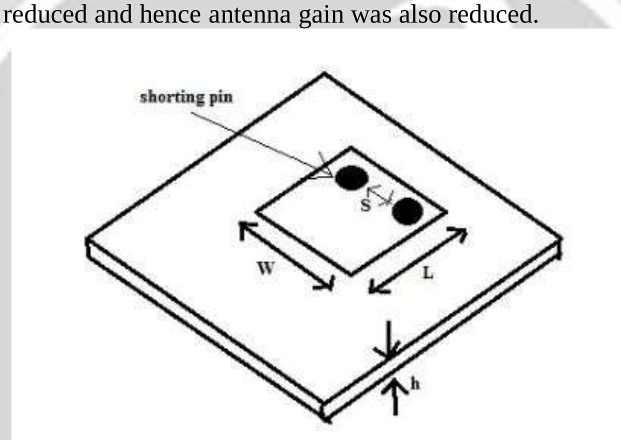

Fig. 3. Quarter wavelength MPA using shorting pins

In [9] single, double and multiple shorting pins were used and results were presented using parametric analysis. Impedance bandwidth, antenna gain was compared and found that size reduction was achieved by factor of 3 with the conventional antenna.

3.4 Introducing slots in the patch method

Changing the shapes of the patch or introducing the slots on the patch is commonly used technique to miniaturize the microstrip patch antenna. By introducing the slots or changing the slots electrical paths for current increases and this can be done using genetic algorithm in high-performance computing method.
In [12] various slots of the different lengths were introduced on the patch of antenna. Also U and L shaped slots were introduced on the ground plane. Here patch and ground plane was shorted ny shorting pin that results in increased electrical path length for current flow and size reduction was achieved up to 86 %. In this antenna was operated on multiple bands of frequencies. The reflection coefficient was found less than -10 dB for all the frequency bands. 3.5 dBi to 6.6 dBi gain was observed for the whole frequency range.
Miniaturized using this method suffers from ohmic losses and that causes reduction in the antenna gain and radiation efficiency for microstrip patch antenna. To solve this problem in [10] artificially engineered conductor was used. Here different layers were laminated separately. Artificially engineered conductor was having same thickness as conventional conductor.
Another method of using slots was presented in [11]. Here they used irregular shapes and size of the slots on the patch of the microstrip patch antenna using genetic algorithm. After introducing slots they simulated the results using finite elements solver HFSS. In this method poor polarization was found.

3.5 Use of Meta-materials

Meta-materials are artificially engineered materials to have a properties which are not readily available. Meta-materials are having negative values of permittivity and permeability. Materials with only negative permittivity is called as ϵ-negative and materials with only negative permeability is called as μ-negative. Materials with both permittivity and permeability negative is called as double-negative. This kind of structure used to achieve high antenna performance and improved radiation efficiency. Also they can be used for miniaturization of patch antenna.
In [13] patch antenna was analysed using meta-material for low frequency domain for the use of LEO and MEO satellite operations for dual transmit and single receive frequency. In this -20 dB return loss was achieved with 80 % size reduction. In [14] this work, open ended rectangular waveguide antenna radiating below its cut-off frequency was investigated. Here square shaped ring resonators or circular shaped ring resonators were used as meta-materials to get size reduction. The investigated open waveguide radiator was designed and simulated using commercial software HFSS^{TM}. They were able to get miniaturization up to 44.5 % of the base radiator. In [15] left handed meta-material with negative refractive index was used to achieve the miniaturization. In this work eight shaped meta-material was designed with the μ_r= -4 and ϵ_r=-2 at 1.8 GHz frequency. At 1.8 GHz frequency they achieved -34 dB return loss and effective volume of the rectangular microstrip patch antenna was shortened by 71 % and 47 % size reduction was achieved to the base substrate of the patch antenna.

4. SUMMARY OF MINIATURIZATION TECHNIQUES

Table 1 summarises various techniques discussed in this paper for miniaturization of microstrip patch antenna. The table highlights the features of each miniaturization methods and lists the advantages and disadvantages of that method. As seen from the table all the techniques lead to miniaturization of patch antenna. Most techniques provide little insight into general design procedure and do not mentioned how these techniques can be applied to the other frequency bands. So more attention should be given into future work. And also many of these techniques only discuss the size reduction of the patch but not of the ground plane. We have to take care of ground plane also because antenna performances also depends on ground plane size.

Table 1. Summary of miniaturization techniques

Miniaturization technique	Features	Advantages	Disadvantages
Use of high ϵ_r material	Higher ϵ_r	Higher size reduction	Expensive, limited Bandwidth
Sierpinski carpet fractal method	Space filling property	Antenna performance maintained	Complex for more iterations
Shorting pins between patch and ground plane	Shorting pins, posts, walls	Cost effective, higher size reduction	No standard procedure
Introducing slots in the patch	Fractal antenna, slots in the patch	Wider Bandwidth	Poor polarization, complex structure
Use of meta-materials	Use of ENG, MNG	Higher miniaturization	Limited bandwidth, lower efficiency

5. CONCLUSION

In this paper we have presented different methods for miniaturization of microstrip patch antenna. Basics of antenna design and transmission line model analysis discussed briefly. The methods used in the literature of antenna miniaturization included modified substrate, use of high permittivity material, sierpinski carpet fractal method, shorting pins, slots in the patch and the use of meta-materials. Some of the methods provided grater miniaturization, whereas the other methods provided moderate level of miniaturization with maintaining antenna performance and radiation efficiency. Some methods are very easy to apply where some are very complex methods for miniaturization, always trade-off will be present that which method user should use, depending on the application in which miniaturized antenna required. We have also pointed out the fact that there is a great need to clearly identify how the various parameters affect the performance of the antenna for a specific miniaturisation technique. Given this background it is safe to predict that challenging problem of miniaturization antenna will continue to draw the attention of researcher for years to come.

.

6. REFERENCES

[1] Sievenpiper, D., Dawson, D., Jacob, M., et al.: ‘Experimental validation of performance limits and design guidelines for small antennas’, IEEE Trans.Antennas Propag., 2012, 60, (1), pp. 8–19

[2] Garg, R., Bhartia, P., Bhal, I., Ittipiboon, A.: ‘Microstrip antenna design handbook’ (Artech House, MA, USA, 2001)

[3] Balanis, C.A.: ‘Antenna theory: analysis and design’ (John Wiley & Sons, NY, USA, 2004, 2nd edn.)

[4] Schaubert, D.H., Yngvesson, K.S.: ‘Experimental study of a microstrip array on high permittivity substrate’, IEEE Trans. Antennas Propag., 1986, AP-34, (1), pp. 92–97

[5] Kula, J., Psychoudakis, D., Liao, W.-J., Chen, C.-C., Volakis, J., Halloran, J.: ‘Patch antenna miniaturization using recently available ceramic substrates’, IEEE Antennas Propag. Mag., 2006, 48, (6), pp. 13–20

[6] Hua-Ming Chen, Yang-Kai Wang, Yi-Fang Lin, Che-Yen Lin, and Shan-Cheng Pan, ‘Microstrip-Fed Circularly Polarized Square-Ring Patch Antenna for GPS Applications’ IEEE TRANSACTIONS ON ANTENNAS AND PROPAGATION, VOL. 57, NO. 4, APRIL 2009

[7] Sika Shrestha, Seung-Jo Han, Sun-Kuk Noh, Sunwoong Kim, Hyun-Bai Kim, Dong-You Choi, ‘Design of Modified Sierpinski Fractal Based Miniaturized Patch Antenna’, IEEE 2013

[8] Ikonen, P.M.T., Rozanov, K.N., Osipov, A.V., Alitalo, P., Tretyakov, S.A.: ‘Magnetodielectric substrates in antenna miniaturization: potential and limitations’, IEEE Trans. Antennas Propag., 2006, 54, (11), pp. 3391–3399

[9] Porath, R.: ‘Theory of miniaturized shorting-post microstrip antennas’, IEEE Trans. Antennas Propag., 2000, 48, (1), pp. 41–47

[10] Latif, S.I., Shafai, L., Shafai, C.: ‘An engineered conductor for gain and efficiency improvement of miniaturized microstrip antennas’, IEEE Antennas Propag. Mag., 2013, 55, (2), pp. 77–90

[11] Wang, D., Wong, H., Chan, C.H.: ‘Small patch antennas incorporated with a substrate integrated irregular ground’, IEEE Trans. Antennas Propag., 2012, 60, (7), pp. 3096–3103

[12] S. Imran Hussain Shah, Shahid Bashir, Amir Altaf, ‘Miniaturization of Microstrip Patch Antenna by Using Various Shaped Slots for Wireless Communication Systems’, IEEE 2014

[13] Trushit K Upadhyaya, Ved Vyas Dwivedi, S. P. Kosta, Y. P. Kosta, 'Miniaturization of Tri band Patch Antenna using Metamaterials', 2012 Fourth International Conference on Computational Intelligence and Communication Networks

[14] Muhammad Abdul Samad, Abdul Kadir Hamid, 'Miniaturization of Waveguide Antenna Using Square/Circular Arrays Of SRR', IEEE 2016

[15] Ruchika Sharma, Harbinder Singh, 'LEFT HANDED METAMATERIAL ANTENNA DESIGN FOR GSM 1.8 GHz APPLICATIONS', oceedings of 2015 RAECS UIET Panjab University Chandigarh 21-22nd December 2015

[16] Muhammad Umar Khan, Mohammad Said Sharawi, Raj Mittra, 'Microstrip patch antenna miniaturisation techniques: a review', IET Microw. Antennas Propag., 2015, Vol. 9, Iss. 9, pp. 913–922