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EMPIRICAL ANALYSIS OF MICROSTRIP PATCH ANTENNA FOR DIFFERENT SUBSTRATE MATERIALS AND SHAPES USING APERTURE COUPLED TECHNIQUE

The dielectric material used as a substrate and the shapes of the patches play an important role in the performance of bandwidth, return loss, and gain of the microstrip patch antenna. This paper presents the relative study of different shapes of microstrip Patch antenna for different dielectric materials. The main application of these antennas is for satellite communication in Ku-Band. The height of the substrate plays an essential role in the enhancement of bandwidth and it is chosen 1.012mm and three substrate materials (RT Duroid (5880), Teflon, and FR4) with different dielectric constants were chosen for the performance comparison. Aperture coupling, which is again one of the promising techniques for bandwidth enhancement, is used as a feeding technique for the designs. Coupling must be taken care of while using aperture coupling, which is done by precisely optimizing the feed line dimensions, feed position, slot dimensions, and patch dimensions. The antenna performance is studied by varying the parameters like patch, feed line, and slot dimensions, the size of the substrate, and the feed line position concerning the slot. Optimization is also performed for the position of the ground layer within the substrate material and the ground plane in the middle position of the substrate is chosen for the final designs. Return loss and impedance matching were analyzed for all designs. The rectangular and circular patches are used for a comparative study, which is conducted from 12GHz to 14GHz out of which the circular patch is found to give better performance. The analysis is carried out for RT Duroid (5880) material and the bandwidth obtained in both cases is almost 3GHz. Similarly, the analysis is carried out for different dielectric materials over the frequencies of 12GHz to 14GHz in which RT Duroid and Teflon give better performance in terms of return loss and FR4 gives better performance in terms of miniaturization. The analysis is carried out for rectangular patches and the bandwidth obtained for FR4 is 1GHz whereas, for RT Duroid (5880) and Teflon, it comes out to be 3GHz. The results are depicted in various tabular and graphical formats. This study is conducted using an HFSS, an electromagnetic solver.

Keywords: *dielectric constant; aperture coupling; bandwidth; return loss; substrate.*

1. Introduction

Microstrip patch antennas having distinct property of small size have been widely used in satellite communications, microwave, radar and aerospace applications. They are easy to fabricate, low in cost, conformal and easy to analyze. The main attractions of these types of antennas include compact size and directive radiation pattern. In this paper, microstrip antenna with different types of patches and different dielectric materials is presented. A microstrip patch antenna has a dielectric substrate with conducting patch of any planar or non-planar geometry on one side and ground plane on other side. This antenna has semi hemispherical radiation pattern and so it is very useful in wireless communication links. Microstrip patch antenna is very popular because of its compactness and efficiency. The name is derived from the fact that a patch is mounted on a ground plane. This antenna has maximum radiation in the broadside direction which is one of the important applications of the wireless communication. Because of this feature, the patch antenna can be fabricated using photolithographic technique. As the antenna can be mounted easily on PCB, it can be made conformal and its cost is also low. The feeding method used is in this paper is aperture coupling. Aperture coupling proves to be one of the promising techniques for bandwidth enhancement [1]. The feed line is one of the important parameters for designing in aperture coupled technique. Fringing field is the other design consideration which is to be taken into account. Fringing field is a function of effective dielectric constant. They can be modeled along the width of the patch and fringing fields in turn increases the length of the radiating element. As the radiation is occurring at the edges, the length of the patch becomes slightly longer than the actual length. The resonant condition can be obtained by matching the feed line and the slot with quarter wavelength [2].

1.1. State of Art

In many researches which are carried out in this domain, slot plays a very important role in changing the surface currents which is described in [3]. The position of slot helps in impedance matching and thus governs the overall radiation efficiency of the antenna [4]. As the shape of the patch also plays a very important for antenna performance, a comparison has be studied in [5]. In addition to this, circular patch has proved to be efficient for energy harvesting as shown in [6]. For all the above observations, it is found that aperture coupled microstrip antenna has many design challenges like slot dimensions and position, patch dimensions and position.

1.2. Objective

The main objective of this work is to study and analyze the behavior of microstrip patch antenna at KU band as this band has proved to be promising for various satellite applications. As aperture coupling proves to be a good feeding technique for bandwidth enhancement, the design is carried out using this technique. Further, as the shape of the patch plays an important role in radiation mechanism of microstrip patch antenna, different shapes is analyzed. In addition to this, dielectric material is very important in the overall performance of the antenna. So the paper in brief describes the performance of various ways of designing microstrip patch antenna.

2. Materials and methods of research

Microstrip antenna is also called patch antenna as the patch is etched on the surface. The patches used on the substrate can vary from various sizes and shapes. The shapes can be rectangular, elliptical, circular or even fractal. Rectangular and circular patches have been represented in this work. The dimensions of patch are adjusted in such a way that patch radiates maximum in broadside direction. The main drawback of these types of antennas is the narrow bandwidth. Because of this, the designing parameters should be such that maximum radiation occurs at the resonant frequency. The microstrip antennas with rectangular shape are made of a rectangular patch, a ground plane, substrate thickness h and dielectric constants εr of the dielectric material. Microstrip antenna has the distinct feature of compact size and so for that the substrate materials should be chosen appropriately.

2.1. Designing parameters

The designing of microstrip patch antenna is carried out using the following designing equations. The resonant frequency and the dielectric material are selected to calculate the width of the patch using equation 1

$$w = \frac{c_0}{2f_r}\sqrt{\frac{2}{\varepsilon_r + 1}}, \tag{1}$$

where w = Width of the patch, c_0= Speed of light,

ε_r = value of the dielectric substrate.

The radiations travel from patch through substrate and air towards the ground plane. So, the effective refractive index is one of the important design parameters. Equation 2 shows the calculation of effective refractive index

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[1 + 12\frac{h}{W}\right]^{-1/2}. \tag{2}$$

The size of antenna increases due to fringing fields and that increase is shown by ΔL in equation 3

$$\frac{\Delta L}{h} = 0.412\frac{(\varepsilon_{eff} + 0.3)\left(\frac{w}{h} + 0.264\right)}{(\varepsilon_{eff} - 0.258)\left(\frac{w}{h} + 0.8\right)}. \tag{3}$$

Here, h is the height of substrate, ΔL is increase in length of the patch.

The length of the patch can be calculated using equation 4

$$L = \frac{c_0}{2f_r\sqrt{e_{eff}}} - 2\Delta L. \tag{4}$$

Finally, the length and the width of the ground plane can be calculated using following equations 5 and 6

$$Lg = 6h + L, \tag{5}$$

$$Wg = 6h + W. \tag{6}$$

Along with this, theantenna should have an appropriate resonant frequency of operation so that miniature structure can be designed. Here, the antenna is mainly designed for Ku-Band applications and so the frequency band selected is 12 GHz to 14 GHz.

2.2. Dielectric material selection

Dielectric material plays an important role in designing because on the basis of the dielectric material chosen, the wave will can absorb and reflected back from the material which will contribute in the radiation of the microstrip antenna. The following parameters are important in selection of dielectric material.

Loss tangent is the measurement of the amount of electromagnetic radiation got lost in the substrate material. All the RF applications need low losses and hence the material with less loss tangent is considered to be appropriate for all the applications.

The relative dielectric constant gives the measurement of how the wave slows down when it travels through the dielectric material due to the capacitance effect. The more the relative dielectric constant, the slower the wave propagation becomes. The dielectric constant affects the dimensions of the patch leading to change in resonant frequency and reduction in transmission efficiency [7, 8]. Fringing field, being the main cause of radiation is also affected by the dielectric constant. The dielectric constant should be lower so that the fringing fields contribute to the most in the overall efficient radiation. In addition to this, the overall gain and bandwidth also reduces if the dielectric constant chosen is of high value. In spite of having many cons on higher value of dielectric constant, there is also a benefit upon increment of dielectric constant which is of the compact size. In this paper, three types of dielectric materials are chosen for various shapes of microstrip patches.

The height of the substrate is directly related to the bandwidth and both are directly proportional to each other. But the care should be taken that increment of height does not lead to spurious radiation. Here the height of the substrate is chosen as 1.012 mm.

The most widely used five microstrip feed techniques: (a) microstrip line feed, (b) inset feed, (c) coaxial feed, (d) aperture coupled feed (e) proximity coupled feed. Aperture coupled technique as shown in Fig. 1 proves to be one of the most promising techniques for improvement of bandwidth [9]. The geometry includes the patch etched on the top with the feed line etched on the bottom. The thickness of both the substrates can be chosen by optimizing so that appropriate resonant frequency can be obtained. The dielectric constant of the substrate mainly affects the bandwidth and the radiation efficiency. Substrate thickness affects the coupling level and hence controls the bandwidth. The length of the patch controls the resonant frequency of the antenna and the width affects the resonance resistance. Many designs use square patch which may lead to high cross polarization levels hence the square patches are mainly used when circular polarization is needed. The other designing factor is the slot dimension in which the length of the slot determines the coupling and therefore the length of the slot should be appropriate in order to avoid back radiation. The ratio of width of feed line to that of slot is typically 1/10. The feed line width affects the coupling of radiation to patch via slot [10]. In many cases, the feed line which is thin couples the slot efficiently. The position of feed line relative to slot also affects the overall radiation, for maximum efficiency, the feed line should be positioned to the right angles with respect to the centre of the slot [11]. In addition to this, the position of patch should be in centre relative to slot in order to achieve maximum radiation [12]. Besides all the above mentioned criteria, many other design criteria are also there which are as discussed here.

2.2.1. Variation in the radiating elements

The radiating elements can be rectangular in shape followed by the circular patches, patches with slots, stacked patches, patches with dipoles and many more. The designs are modified mainly to achieve better bandwidth.

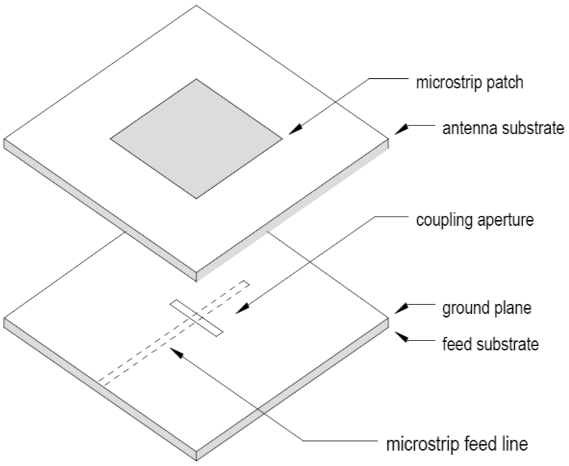

Fig. 1. Aperture Coupled Patch Antenna

2.2.2. Slot shape

Slot being the main element in coupling the radiation should be chosen appropriately. The slots with various designs and shapes like the h shaped, bow shaped etc. can also used to improve coupling.

2.2.3. Dielectric layers

The aperture coupled antenna can use multiple layers in order to increase the performance. Many techniques like use of foam, stacking the dielectric layers have proved to be efficient in increasing bandwidth.

3. Antenna Design

The work has been carried out for comparison of different dielectric materials like FR4 (Flame Retardant), RT Duroid (5880) and Teflon [13] The feeding technique used here is aperture coupling. The following table shows the dielectric constant and loss tangent of different dielectric materials used in this paper.

As can be seen from Table I it is reflected that RT Duroid and Teflon exhibit lower loss tangent as their dielectric constants are less compared to FR4.

Table I

Dielectric materials specifications

Sr. No.	Material	Dielectric Constant	Loss tangent
1	FR4	4.4	0.02
2	RT Duroid	2.2	0.009
3	Teflon	2.1	0.001

Different designs have been simulated for Ku band and the dimensions of all the parameters for different designs are shown in Table II. As the designs have been carried out for two different types of patches, rectangle and circle [13], the dimensions will be shown in two Tables (II and III) respectively.

Table II

Design specifications of rectangular patch

Parameter	W	L	W	L	W	L
	RT Duroid (mm)		Teflon (mm)		FR4 (mm)	
Patch	7.8	7.8	7.5	7.8	5.8	6
Strip line	1.5	6.85	1.5	6.85	1	5.5
Slot	5	1	5	1	3	0.6
Substrate	8	8	8	8	6	6

The Table II shows the design specifications of rectangular patch for different dielectric materials. As, the feeding technique used is aperture coupled, the strip line and the slot becomes the main parameters for variation. Slot is the coupler between two layers of substrate material. It joins the strip line to the patch. The cross shaped formed by the feed line and the slot decides the coupling from strip line to the slot. Hence, a proper impedance matching should be done between feed line and the slot.

Table III

Design specifications of circular patch

Sr. No.	Parameter	Radius (mm)	Width (mm)	Length (mm)
1	Patch	4	-	-
2	Strip line	-	1.5	6.85
3	Slot	-	5	1
4	Substrate	-	8	8

The Table III shows the design specifications of the circular patch for RT Duroid substrate. The circular patch has the radius of the circle as the design parameter varies. In this case also, the slot and strip line coupling play an important role in the overall efficiency of the antenna. A proper matching between the slot and the strip line should be done.

4. Results and Discussion

The results are divided into two parts. One is the comparison between different shapes of the patches and other is comparison between different dielectric materials. Return loss graphs are presented for the rectangular patch aperture coupled design and circular patch aperture coupled design.

Results of two different shapes of patches have been analyzed and tabulated in Table IV.

Table IV

Results for different shapes of patch

Shape of the patch	Type of dielectric material	Band-width	Return loss (dB)
Rectangular	RT Duroid	3 GHz	-52.8
Circular	RT Duroid	3 GHz	-62

Both the designs give a good return loss and bandwidth obtained in both the cases is also around 3GHz. The same result has been shown in Fig. 2 which is the graphical representation of the comparison. The results clearly show that circular patch gives better performance in terms of return loss. It has also been observed that the circular patch had 3dB higher return loss compared to rectangular patch for aperture coupled feeding technique. The dotted line in Fig. 2 shows the graph for rectangular patch and the red colored solid line shows the graph for circular patch. In addition to this, the circular patches prove to be more promising in terms of ease of the design as it has only one parameter, the radius which is to be optimized. The next discussion is on different types of dielectric materials.

The different dielectric materials are used here for performance comparison. Table V shows the return loss and bandwidth obtained for three different types of dielectric materials.

It can be seen from Table V that, amongst the three materials, the bandwidth and return loss from RT Duroid and Teflon are better compared to the results of FR4 and it is because of the low dielectric constant.

However, Teflon exhibits better results compared to RT Duroid in terms of return loss. It gives almost 11 dB higher return loss compared to RT Duroid. The same results have been graphically represented in Fig. 3 as shown.

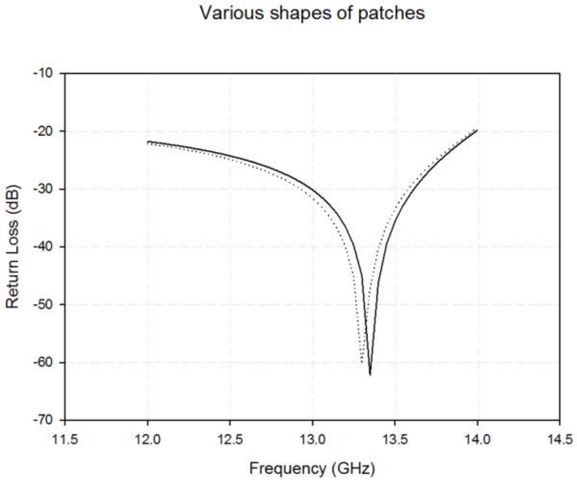

Fig. 2. Return loss graph
for different shapes of patches

Table V

Results for different shapes of patch

Shape of the patch	Type of dielectric material	Bandwidth	Return loss (dB)
Rectangular	FR4	1.1GHz	-26.5
Rectangular	RT Duroid	3GHz	-52.8
Rectangular	Teflon	3GHz	-63.75

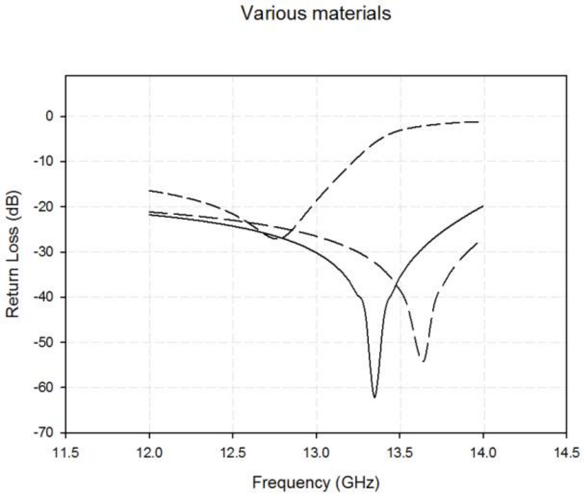

Fig. 3. Return loss graph for different dielectric materials

The three graphs are represented by different types of lines. The straight line represents the results for Teflon material. The fewer dotted linesrepresent the results for RT Duroid and the intensely dotted line represents the results for FR4.

5. Conclusions

An observation in carried out on the effects of changing dielectric materials and its performance on the bandwidth and the return loss, using aperture coupled feeding technique at KU band which is mainly used for satellite applications. The lower the dielectric constant, the better the performance of antenna. It is also observed that RT Duroid and Teflon give better performance compared to FR4. The return loss and the bandwidth achieved in the RT Duroid and Teflon are better than FR4. However, Teflon proves to give better performance in terms of return loss when compared to RT Duroid. In addition to this, when the miniaturization of structure is to be done, FR4 proves to be the best as the design is compact compared to other dielectric materials. Again, FR4 proves to be cost effective compared to the other two materials. It is also having ease of availability. Hence, dielectric material being a vital element in designing of microstrip patch antenna, it should be chosen accurately and sufficient design optimization should be carried out in order to achieve maximum efficiency. In addition to this, the shape of the patch is also important. In this work, a comparison between rectangular and circular patch has been presented and circular patch proves to be little bit more promising in performance at KU band. As shown in [14, 15], this work can be extended in checking the performance of array structures and such types of antennas can be integrated in the radar systems.

5.1. Future Research Directions

This work can be extended in checking performance for array structure for all available designs. Again, the shapes of the patches can be modified in order to analyse the performance. The feeding technique can also be changed to study.

Contribution of authors: selection of shapes and method for bandwidth enhancement, selection of software tool and designing, simulating and optimizing the design to appropriate level – **P. Pandya**; review and analysis of the design – **M. Saradadevi**; formulation of conclusion, content of the paper, review and analysis of the design – **N. Langhnoja**. All authors have read and agreed to the published version of the manuscript.

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ЭМПИРИЧЕСКИЙ АНАЛИЗ МИКРОПОЛОСОВОЙ ПАТЧ-АНТЕННЫ ДЛЯ РАЗЛИЧНЫХ МАТЕРИАЛОВ И ФОРМ ПОДСТРОЙКИ С ИСПОЛЬЗОВАНИЕМ АПЕРТУРНО-СВЯЗАННОЙ ТЕХНИКИ

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Диэлектрический материал, используемый в качестве подложки, и формы патчей играют важную роль в характеристиках полосы пропускания, обратных потерь и коэффициента усиления микрополосовойпатч-антенны. В этой статье представлено относительное исследование различных форм микрополосовыхпатч-антенн для различных диэлектрических материалов. Основное применение этих антенн – спутниковая связь в Ku-диапазоне. Высота подложки играет очень важную роль в расширении полосы пропускания, и она выбрана равной 1,012 мм, а для сравнения производительности выбраны три материала подложки (RT Duroid (5880), тефлон и FR4) с различными диэлектрическими постоянными. Связь с апертурой, которая снова является одним из многообещающих методов расширения полосы пропускания, используется в качестве метода подачи для конструкций. При использовании апертурного соединения необходимо следить за соединением, которое достигается путем точной оптимизации размеров линии подачи, положения подачи, размеров прорези и размеров патча. Характеристики антенны изучаются путем изменения таких параметров, как размер патча, фидерной линии и прорези, размер подложки и положение фидерной линии по отношению к прорези. Оптимизация также выполняется для положения слоя грунта в материале подложки, и для окончательного дизайна выбирается среднее положение. Обратные потери и согласование импеданса анализируются для всех конструкций. Прямоугольные и круглые патчи используются для сравнительного исследования, которое проводится в диапазоне от 12 ГГц до 14 ГГц, из которых было обнаружено, что круговой патч дает лучшую производительность. Анализ выполнен для материала RT Duroid (5880), и в обоих случаях полученная полоса пропускания составляет почти 3 ГГц. Аналогичным образом анализ проводится для различных диэлектрических материалов на частотах от 12 ГГц до 14 ГГц, в которых RT Duroid и Teflon обеспечивают лучшие характеристики с точки зрения обратных потерь, а FR4 обеспечивает лучшие характеристики с точки зрения миниатюризации. Анализ проводится для прямоугольного патча, и полоса пропускания, полученная для FR4, составляет 1 ГГц, тогда как для RT Duroid (5880) и Teflon она составляет 3 ГГц. Результаты отображаются в различных табличных и графических форматах. Это исследование проводится с использованием HFSS, электромагнитного решателя.

Ключевые слова: диэлектрическая проницаемость; апертурная связь; полоса пропускания; обратные потери; подложка.

ЕМПІРИЧНИЙ АНАЛІЗ МІКРОСМУЖНОЇ ПАТЧ-АНТЕНИ ДЛЯ РІЗНИХ МАТЕРІАЛІВ І ФОРМ ПІДНАЛАШТУВАННЯ З ВИКОРИСТАННЯМ АПЕРТУРНО-ЗВ'ЯЗАНОЇ ТЕХНІКИ

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Діелектричний матеріал, що використовується як підкладка, і формипатчей відіграють важливу роль у продуктивності смуги пропускання, зворотних втрат та коефіцієнта посиленнямікросмужковоїпатч-антени. У цій роботі представлено відносне дослідження різних форм мікросмужковоїпатч-антени для різних діелектричних матеріалів. Основне застосування цих антен – для супутникового зв'язку в Ku-діапазоні. Висота підкладки відіграє дуже важливу роль у збільшенні пропускної здатності, і її вибирають 1,012 мм, а для порівняння продуктивності вибирають три матеріали підкладки (RT Duroid (5880), тефлон і FR4) з різними діелектричними проникненнями. З’єднання апертур, яке знову ж таки є одним із перспективних методів для збільшення пропускної здатності, використовується як техніка подачі для проектів. Під час використання апертурного з’єднання необхідно подбати про з’єднання, яке здійснюється шляхом точної оптимізації розмірів лінії подачі, положення подачі, розмірів отворів і розмірів латки. Ефективність антени вивчається шляхом зміни таких параметрів, як патч, розміри лінії живлення та гнізда, розмір підкладки та положення лінії живлення щодо гнізда. Оптимізація також виконується для розташування шару грунту в матеріалі підкладки, а середнє положення вибирається для остаточного дизайну. Для всіх конструкцій аналізуються зворотні втрати та узгодження імпедансу. Прямокутні та круглі патчі використовуються для порівняльного дослідження, яке проводиться від 12 ГГц до 14 ГГц, з яких круговий патч дає кращу продуктивність. Аналіз проведено для матеріалу RT Duroid (5880), отримана смуга пропускання в обох випадках становить майже 3 ГГц. Аналогічно, аналіз проводиться для різних діелектричних матеріалів на частоті від 12 ГГц до 14 ГГц, в яких RT Duroid і Teflon забезпечують кращу продуктивність з точки зору зворотних втрат, а FR4 – кращу продуктивність з точки зору мініатюризації. Аналіз проведено для прямокутного патча, і пропускна здатність, отримана для FR4, становить 1 ГГц, тоді як для RT Duroid (5880) і Teflon вона виявляється 3 ГГц. Результати відображаються в різних табличних і графічних форматах. Це дослідження проводиться за допомогою HFSS, електромагнітного вирішувача.

Ключові слова: діелектрична проникність; апертурна зв'язок; смуга пропускання; зворотні втрати; підкладка.

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