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ANALYTICAL METHODS FOR BANDWIDTH ENHANCEMENT OF MICROSTRIP PATCH ANTENNA

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Abstract

Microstrip Patch Antennas have been used extensively in wireless communication systems due to its advantages of being low profile and cost effective but the antenna suffers from the limitation of low bandwidth. Feeding technique is one of the criteria to be chosen while designing microstrip patch antenna. The paper presents various designs to enhance bandwidth for KU band 12 GHz to 14.5 GHz. Simple microstrip line feed and aperture coupled feed are two techniques which are used to design the antenna, their comparison is done for bandwidth enhancement. Further, analysis and results based on various shapes of patches and height of substrate is also presented.

Keywords.

Feeding Techniques, Bandwidth, Aperture Coupled, Slot, Shapes, Return Loss

1. INTRODUCTION

Antennas being the fundamental elements of wireless communication systems, low profile confirms to be foremost features [1]-[2]. Microstrip patch antennas shown in Fig.1 are one of the most promising antennas of this category. It is the antenna with low profile and low cost which is used for various wireless communication systems like satellite, microwave and mobile. Further, these antennas are easy to accommodate with other microstrip circuit elements and thus can be easily integrated into a system [3].

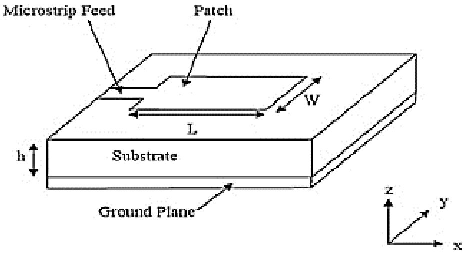

Fig.1. Microstrip Patch Antenna

Microstrip antennas are tranquil to use in arrays in order to increase directivity. These antennas have a critical shortcoming of low bandwidth. Various methods have been used to enhance the bandwidth, some of which include increase in the thickness of substrate, use of dielectric materials with low losses, use of various feeding techniques and different shapes and sizes of patch [4]. For higher transmission data rates, the gain and efficiency are most important factors. The feeding methods play an important role for efficient working of microstrip patch antennas [5].

An appropriate consideration should be made on designing part. The feed element can be either in same plane or in different plane with respect to the radiating patch and coupling of energy can be done. The feeding is mainly divided into Inset feed, Microstrip line feed, Aperture Coupled feed and Proximity feed.

Microstrip line feed is the basic feeding method used with microstrip patch antenna which consists of strip line which is in the same plane as the radiating patch. Inset feed is the design used with notch between the strip line and the patch in order to adjust the impedance. Aperture coupled and proximity coupled feeds use the coupling mechanism to deliver the radiation from strip line to the radiating patch. In these two methods, the patch and the strip line are non-co-planar

2. ANTENNA DESIGN

The designing of microstrip patch antenna can be done using different feeds as well as using patches of various shapes and sizes. Microstrip Antenna consists of a radiating element on the substrate [6] and the ground plane is situated on the other side. In order to enhance bandwidth, various methods are used [7]. In probe fed microstrip antenna, the ground and the surface are connected by probe, which leads to reactance of the probe. This leads to decrease in efficiency and in turn reduction in bandwidth. The microstrip line feed technique can be used in which the patch is fed with micro strip line [8]-[9].

In aperture coupled microstrip antenna, the feed line is not in direct contact with the patch. It can reduce the discontinuity occurring due to direct current contact [10]. The indirect contact leads to individual parameter optimization. Aperture coupled patches are used widely in arrays such as phased arrays and reflect arrays as it can provide phase shift variations.

Amongst many shapes of patches, the rectangular and circular patches are widely used in designing as they can be operated over a wide range of frequencies [11]. Further, impedance matching can be easily achieved with these type of patches as well as these kind of patches can easily be used to achieve linear and circular polarizations. The designing equations can be used to calculate the initial dimensions. The width of the patch plays a very important role in radiation and it can be calculated by using the Eq.(1).

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

The next important parameter to be calculated is the effective refractive index. It is the medium for the signal to travel from the feed line to the patch. It affects the overall efficiency of the antenna. It is related to the width and height of the antenna. So, after the calculation of the width, effective refractive index can be calculated using the Eq.(2).

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

Due to the radiation from the edges, the fringing fields' increases and it leads to virtual increase in the length of the patch.

The equation for the increase in length of the patch is given as shown in Eq.(3).

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

As, ΔL has been introduced because of the fringing fields, the length L of the patch becomes as shown in Eq.(4).

$$L=\frac{c_0}{2f_r\sqrt{e_{eff}}}-2\Delta L \qquad (4)$$

The effective length and width of the antenna can be given by the Eq.(5) and Eq.(6).

$$Lg=6h+L \qquad (5)$$

$$Wg=6h+W \qquad (6)$$

Circular patches have also found many applications in array structures. The design controlling parameter for circular patch is its radius. Cavity model is one of the efficient techniques which is used to analyze the antenna performance. For circular patch, the cavity can be considered as the two circular cavities and the analysis is done [12]. The equation for circular patch radius calculation is as given below.

$$\frac{F}{\sqrt{1+\frac{2h}{\pi a\varepsilon_r}\left[\ln\frac{\pi F}{2h}+1.7726\right]}} \qquad (7)$$

The designing of antenna can be started by deciding the frequency. Once the frequency is fixed, the dimensions of patch can be derived using designing equations. In the paper, the designing is done for 12 GHz to 14 GHz KU band [13]-[14]. The dielectric material used is FR4 (Flame Retardant). The length and width for center frequency 12.8 GHz comes out to be 5.15 mm and 7.12 mm respectively. These parameters may vary while going for actual designing in the tool. The height of antenna is chosen to be 1.012 mm after doing a parametric study.

3. VARIOUS FEEDING TECHNIQUES

3.1 MICROSTRIP LINE FEED

The paper mainly focuses on comparative study of microstrip antenna using various parameters like feeding techniques and shapes. The Microstrip line fed design is done as shown in Fig.2.

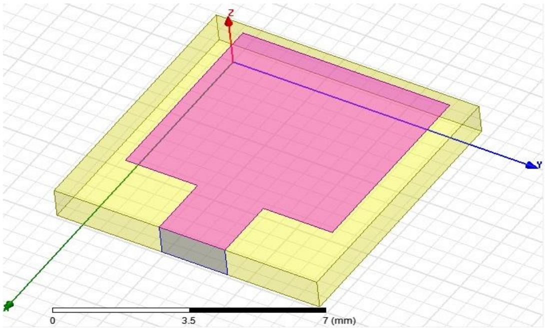

Fig.2. Simple Fed Microstrip Patch Antenna design

Microstrip line feeding technique is single layered structure in which feeding is given through a strip line. The patch lies on the top which is the main radiating part. There should be proper impedance matching between the microstrip line and the patch for effective radiation [15]. The advantage is the simple design and because of this, it can be easily used with arrays. The Table.1 shows the specifications of the design.

Table.1. Design specifications for Microstrip line feeding technique

Patch (mm)		Strip line (mm)		Port (mm)		Substrate (mm)	
W	***L***	***W***	***L***	***W***	***L***	***W***	***L***
5.8	6.3	2	1.9	2	1.01	8	8

The impedance matching can easily be obtained in this feeding technique. It has drawback of narrow bandwidth as the height of the substrate comes to a limitation in this technique. Even though the design is simple, the patch and the microstrip line should be optimized properly in order to prevent feed line from radiating at discontinuities.

3.2 APERTURE COUPLED FEED

The other design carried out is using aperture coupled patch antenna. Aperture coupled is the multilayered structure as shown in Fig.3. In aperture coupling technique, the feed line and the patch are separated with a ground plane with slot [16]. On both the sides of ground plane lies the dielectric material. The dielectric layers can be of the same material or of different materials. Aperture coupled antenna doesn't have direct contact of the feed line and patch, instead a slot is used which can couple waves from feed line to the patch [17]. It provides the strongest coupling than any other structure as the aperture is positioned where the concentration of fields from feed line is higher.

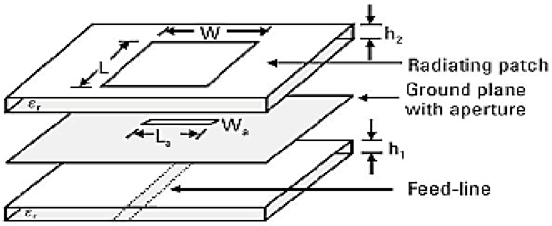

Fig.3. Basic Image of Aperture Coupled Patch Antenna

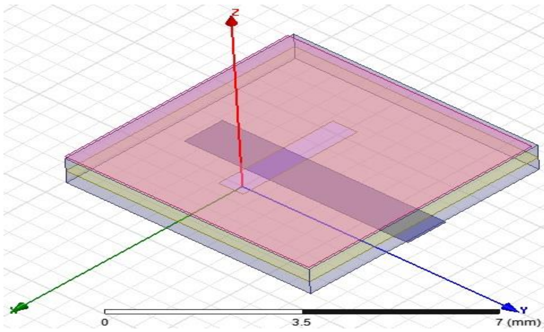

Fig.4. Aperture Coupled Patch Antenna design with rectangular patch

Aperture coupled patch have the advantage of its increased bandwidth. Aperture coupled provides additional room for designing compared to probe fed and coaxial fed patch antennas [18]. The slot plays a very important role in coupling the signals from feed line to the patch. The cross formed between the slot and the feed line plays a major role in impedance matching. In addition to this, the number of dielectric layers can also affect the radiation and efficiency. In Fig.4, two layers of dielectric materials are used.

Aperture coupling provides thickness better than any other feeding techniques and thus it contributes in gain bandwidth enhancement [19]-[20]. Though it has complex design, the parameters can be adjusted to obtain appropriate gain bandwidth. The Table.2 highlights the design specifications of aperture coupled design.

Table.2. Design specifications for Aperture Coupled with rectangular patch feeding technique

Patch (mm)		Stripline (mm)		Slot (mm)		Substrate (mm)	
W	***L***	***W***	***L***	***W***	***L***	***W***	***L***
5.85	6	1	5.5	3	0.6	6	6

3.3 DIFFERENT SHAPES OF PATCHES

As aperture coupled patch provides better bandwidth and room for parametric analysis, the same feeding technique is used with circular shaped patch as shown in Fig.4 [21]. The specifications are shown in Table.3. The design with rectangular patch is already shown in Fig.5.

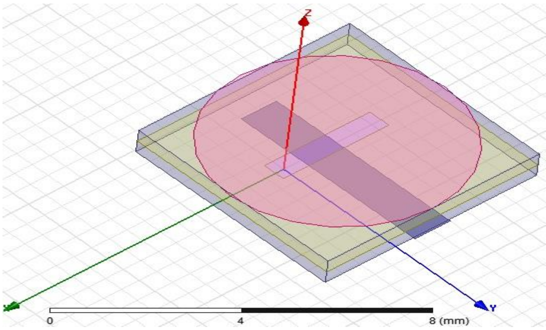

Fig.5. Aperture Coupled Microstrip Antenna with circular patch

For rectangular patch, the length and the width of patch are taken into consideration whereas for circular patch, the radius and number of turns are taken into consideration.

Table.3. Design specifications for Aperture Coupled with circular patch feeding technique

Patch (mm)	Stripline (mm)		Slot (mm)		Substrate (mm)	
Radius	***W***	***L***	***W***	***L***	***W***	***L***
3.05	1	5.5	3	0.6	6	6

The parameter used to control the design is the radius of the circular patch.

3.4 DIFFERENT HEIGHT OF SUBSTRATE

The height of the substrate is one of the important parameters to control the bandwidth. The height and bandwidth are related by the Eq.(8).

$$\frac{h}{\lambda_0} < \frac{1}{4\sqrt{\varepsilon_r - 1}} \tag{8}$$

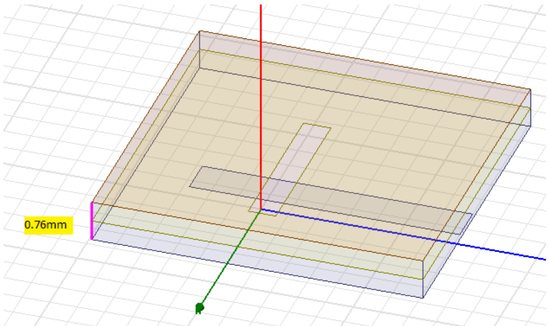

Fig.6. Aperture Coupled Patch Antenna design with height variation

Fig.6 shows the design of aperture coupled rectangular patch antenna with height 0.76mm. As far as the above equation is satisfied, the height of the substrate can be increased [22-23-24]. The care should be taken while designing that spurious radiation doesn't occur from the antenna after increment in the height. The specifications of the design are given in Table.4.

Table.4. Design specifications for Aperture Coupled with rectangular patch feeding technique with height 0.76mm

Patch (mm)		Stripline (mm)		Slot (mm)		Substrate (mm)	
W	***L***	***W***	***L***	***W***	***L***	***W***	***L***
5.85	6	0.7	4.9	3	0.5	5.85	6

4. RESULTS

The dimensions of all the designs are simulated using HFSS simulator [25].

3.5 MICROSTRIP LINE FEED

The parameters used to control the microstrip line feed design mainly include the strip line length and width variation as well as the length and width of the patch. The feed line controls the return loss of the antenna. The return loss should be less in order to increase efficiency. The port dimensions control the overall bandwidth. The port again should be matched with the feed line in order to increase bandwidth. The working band is controlled by the height of the antenna and finally the patch controls the centre frequency. This technique gives 0.1GHz bandwidth which is considered onwards from -15dB. The return loss graph of this design is shown in Fig.7. The matching is mainly provided by controlling the dimensions of patch. The return loss graph gives -21.2dB at the centre frequency of 12.7 GHz.

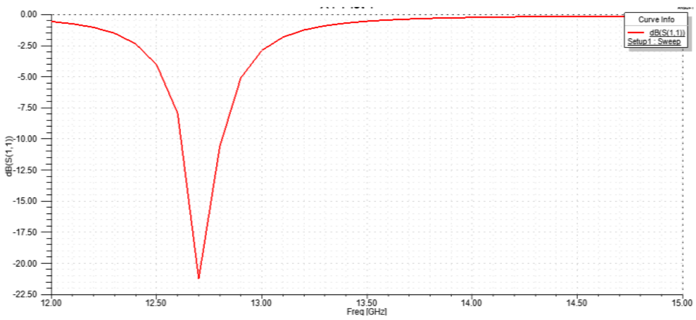

Fig.7. Return Loss Graph for Inset Fed Microstrip Patch Antenna

3.6 APERTURE COUPLED USING RECTANGULAR PATCH

The aperture coupled feeding technique has many parameters that can be varied in order to obtain appropriate design. The patch used is rectangular in shape.. The feed line and the slot dimensions control the gain and bandwidth of the antenna. The patch controls the centre frequency and the working band is controlled by the height of the antenna. The return loss when measured from -15dB gives range from 12 GHz to 13.1 GHz. The optimization is done by controlling the patch, feed line and the slot. The cross shape formed between the slot and the feed line is the main parameter for controlling the impedance matching.

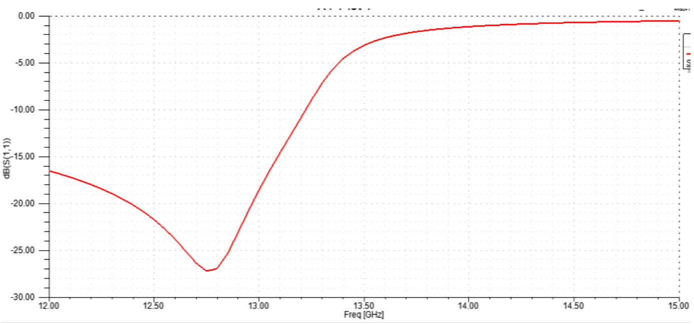

Fig.8. Return Loss Graph for Aperture Coupled Microstrip Antenna with rectangular patch

The bandwidth obtained for the aperture coupled patch is 1.1 GHz as shown in Fig.8. The return loss is obtained as -26.8dB at the centre frequency.

3.7 APERTURE COUPLED USING CIRCULAR PATCH

The patch used for the antenna can be varied. The following result is for the circular patch in order to achieve adequate bandwidth. The parameters used to control the design are same as that for the rectangular patch. Fig.9 shows the return loss graph for circular patch which is obtained as -26.8dB for centre frequency of 12.8GHz.

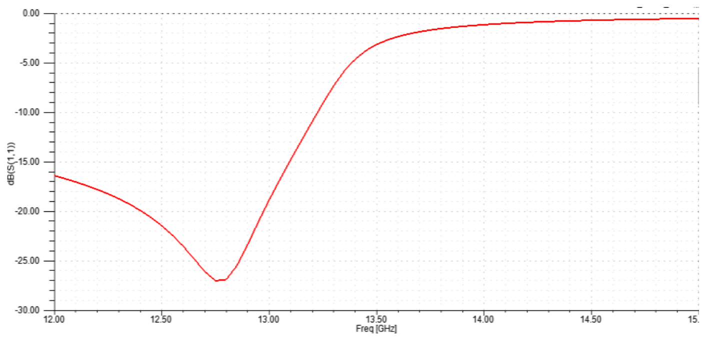

Fig.9. Return Loss Graph for Aperture Coupled Microstrip Antenna with rectangular patch

The bandwidth obtained for circular patch is 1.1 GHz. The results are much similar to that of the rectangular patch.

3.8 APERTURE COUPLED USING VARIOUS HEIGHT

The next result is for variation of the height of the patch. As height plays an important role in the bandwidth enhancement, a suitable height should be selected for the antenna. The return loss graph for the substrate of height 0.76mm is shown in Fig.10. The design gives the return loss of -21.2dB at the frequency of 14.4 GHz. As the substrate is divided by ground plane, the symmetrical division or asymmetrical division also controls the performance of antenna in terms of bandwidth.

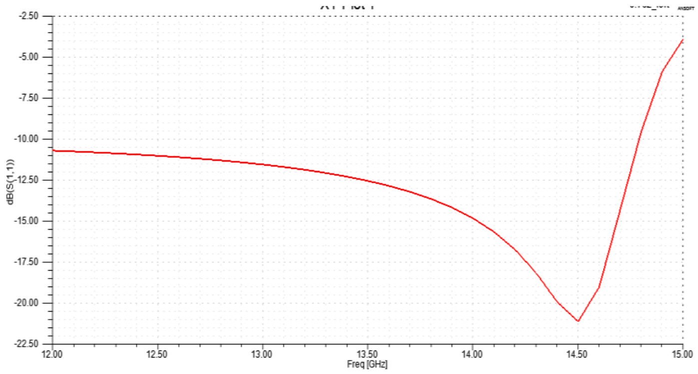

Fig.10. Return Loss Graph for Aperture Coupled Microstrip Antenna with rectangular patch and height 0.76mm

The bandwidth obtained in this case is 0.7GHz. The comparison can be seen properly in the Table.5 - Table.7.

Table.5. Comparison of various types of feeding techniques

Feed type	Patch Shape	Resonance frequency	Return Loss	Bandwidth
Inset	Rectangular	12.7 GHz	-21.2 dB	0.1GHz
Aperture	Rectangular	12.8 GHz	-26.5 dB	1.1GHz

The results show that the aperture coupled microstrip patch antenna provides more bandwidth than the microstrip line fed design because of increment in the height of antenna. The optimized return loss in the case of aperture coupled feed is higher as shown in Table.5.

Table.6. Comparison of Various shapes of patches

Patch Shape	Feed type	Resonance frequency	Return Loss	Bandwidth
Rectangular	Aperture	12.8 GHz	-26.5 dB	1.1GHz
Circular	Aperture	12.8 GHz	-26.8 dB	1.1GHz

When moving on to the shape comparison, both the circular as well as rectangular patches gives the same results of return loss and bandwidth which is shown in Table.6. But, when used in array structure, the circular patches exhibit mutual coupling and less radiating area than the rectangular patch.

Table.7. Comparison of heights of substrates

Patch Shape	Height	Resonance frequency	Return Loss	Bandwidth
Rectangular	0.76mm	14.4 GHz	-21.1dB	0.7 GHz
Rectangular	1.012mm	12.8 GHz	-26.8 dB	1.1GHz

When bandwidth is to be focused as performance parameter, height of the antenna plays a very important role. From Table.7, it can be seen that as height increases the performance of the antenna in terms of bandwidth as well as return loss also increases.

5. CONCLUSION

The paper gives a comparative analysis of different designs of microstrip patch antenna. It is also observed that though the microstrip line fed is simple in design, it lacks in achieving good bandwidth. Aperture coupled design provides greater bandwidth as the height of an antenna is increased. The parameters governing the design are also presented in results and discussion. The bandwidth for both the cases comes out to be 0.1GHz for microstrip line feed and 1.1GHz for Aperture coupled feed. Further, different shapes of the patch give almost identical results. But rectangular patch is preferred over circular patch for the ease of designing. All the designs give adequate return loss which is around -21dB to -27dB. A comparison between different heights is also shown and it's seen as height of substrate is increased in its range, the bandwidth of the antenna increases.

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