Design and Simulation of a Low Cost Three Band Microstrip Patch Antenna for the X-band, Ku-Band and K- Band Applications

M.A.Motin,[1*] Md. Imran Hasan,[2] and Md. Shariful Islam[3]

[1,3]EEE, Rajshahi University of Engineering & Technology
Rajshahi-6204, Bangladesh

[2]ETE, Rajshahi University of Engineering & Technology
Rajshahi-6204, Bangladesh
motin_eee_06@yahoo.com

Abstract—**The aim of this paper is to design the effective shape of a microstrip patch antenna which can provide lower return losses, better gain and performance for X-band (2 GHz to12 GHz), Ku-band (12 GHz to 18 GHz) and K-band (18 GHz to 26 GHz) applications. Attempts have been made to optimize the antenna performance by increasing the number of slots, by using slots in different position in patch and by using array technique. The simulation is performed by using GEMS simulator which is commercially available antenna simulator. The antenna is designed by using Taconic TLY-5 dielectric substrate with permittivity ε_r =2.2 and height, h=1.588 mm. Without using array technique we have got the return losses in the range of -20 db to -25 db at the frequencies around 19.5 GHz. The series feed array offers -7.25 db return loss around 11.5 GHz, -17.5 db return loss around 16 GHz and -13db return loss around 21GHz. Therefore, this antenna is suitable for X-band, Ku-band and K- band applications.**

***Keywords*—Microstrip patch antenna, Series feed array antenna, X-band, Ku-band, K-band**

I. Introduction

Antennas are our electronic eyes and ears on the world. They are our links with space. They are an essential, integral part of our civilization [1]. With the rapid growth of the wireless communication system the future technologies need a very small and multiband antenna. Nowadays, people demand multiband wireless phone supporting more than one network, having different frequencies and simultaneous transmission of audio, video and data. These services are possible with the help of microstrip patch antenna having multiband characteristics. Modern wireless communication system also requires low profile, light weight, high gain, ease of installation, high efficiency, simple in structure to assure reliability and mobility characteristics. Microstrip antennas satisfy such requirements. The key features of a microstrip antenna are low profile, relative ease of construction, low weight, comfortable to planar and non planar surfaces, low cost, simple and inexpensive to manufacture by using printed circuit board. These advantages of microstrip antennas make them popular in many wireless communication applications such as satellite communication, radar, medical applications, aircraft, spacecraft, and missile applications. Many researchers have designed a single element patch in different way to gate multiband application such as double PIFA [2], U-slot [3], double U slot, E slot, H slot and other structures. In this paper an investigation on the design of microstrip array antenna to control two bands by matching the impedance of successive elements and using the quarter wavelength transformer method is made. The goal of this paper is to decrease the size of the antenna and at the same time to improve the radiation performance of the patch antenna in terms of directivity, maximum radiation, return loss and efficiency. As an advantage, the resonant frequency of this antenna can be easily controlled by either increasing of decreasing some parameters such as width and length of the each element. Here the designed antenna supports three bands at 11.5 GHz, 16 GHz and 21 GHz. So this designed antenna is able to meet the demand of X-band, Ku-band and K-band applications.

978-1-4673-1436-7/12/$31.00 ©2012 IEEE

II. Microstrip Patch Antenna Design

Microstrip patch antennas consist of very thin metallic strip (patch) placed above a ground plane where the thickness of the metallic strip is restricted by t<< λ_0 and the height is restricted by $0.003\lambda_0 \leq h \leq 0.05\lambda_0$ [4, 5]. The microstrip patch is designed so its pattern maximum is normal to the patch (broadside radiator). For a rectangular patch, the length L of the element is usually $\lambda 0/3 < L < \lambda 0/2$. The strip (patch) and the ground plane are separated by a dielectric sheet (referred to as the substrate. There are numerous substrates that can be used for the design of microstrip antennas, and their dielectric constants are usually in the range of $2.2 \leq \varepsilon_r \leq 12$. The ones that are most desirable for good antenna performance are thick substrates whose dielectric constant is in the lower end of the range because they provide better efficiency, larger bandwidth, loosely bound fields for radiation into space, but at the expense of larger element size. Thin substrates with higher dielectric constants are desirable for microwave circuitry because they require tightly bound fields to minimize undesired radiation and coupling, and lead to smaller element sizes; however, because of their greater losses, they are less efficient and have relatively smaller bandwidths

The antenna has a simple structure fed by 50Ω microstrip line. The dimensions of the proposed antenna used for theoretical, simulated and practical study are in mm range. The dielectric material selected for design is Taconic TLY-5 which has dielectric constant of 2.2 and the height of dielectric substrate is 1.588mm. The overall dimension of the antenna is 17.6 x 4.9 x 1.988mm. Here GEMS simulator is used to obtain the return loss and gain.

For an efficient radiation a practical width of the Rectangular patch element becomes [5]

$$w = \frac{1}{2 f_r \sqrt{\mu_0 \varepsilon_0}} \times \sqrt{\frac{2}{\varepsilon_r + 1}} \tag{1}$$

And the length of the antenna becomes [4, 5, 6]

$$L = \frac{1}{2 f_r \sqrt{\varepsilon_{eff}} \sqrt{\varepsilon_0 \mu_0}} - 2\Delta L \tag{2}$$

Where

$$\Delta L = 0.41h \frac{\varepsilon_{eff} + 0.3}{\varepsilon_{eff} - 0.258} * \frac{\left(\frac{w}{h} + 0.264\right)}{\left(\frac{w}{h} + 0.8\right)} \tag{3}$$

And

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2\sqrt{1 + 12\frac{h}{w}}} \tag{4}$$

Where, λ is the wave length, f_r (in Hz) is the resonant frequency, L and W are the length and width of the patch element, in mm, respectively and ε_r is the relative dielectric constant.

III. SINGLE ELEMENT MICROSTRIP PATCH ANTENNA

Fig. 1 shows an antenna that has been designed to cover operating frequency of 19.5 GHz and quarter wave length transformer method is used to match the impedance of the patch element with transmission line.

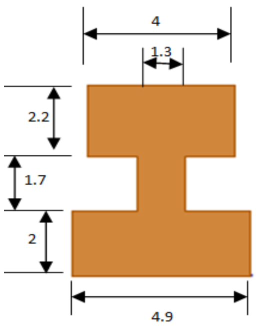

Fig . 1 Single element microstrip patch antenna

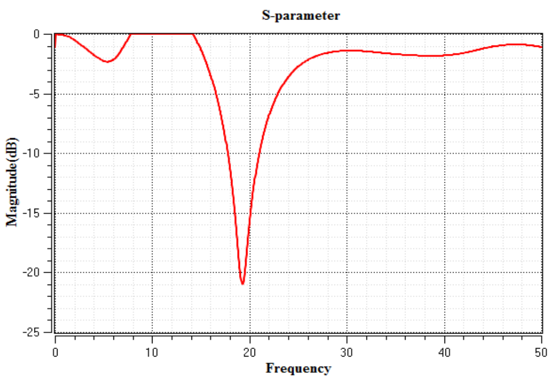

Fig . 2 Return loss of a single element microstrip patch antenna

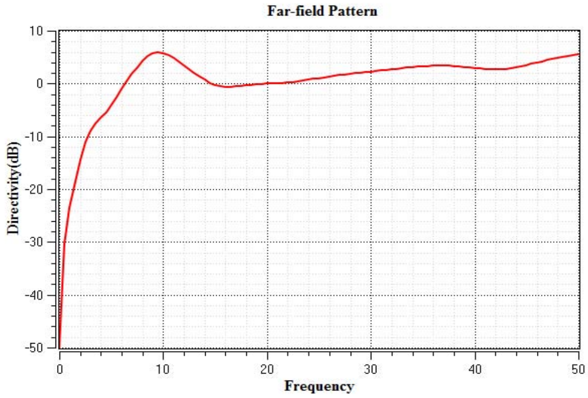

Fig . 3 Gain of a single element microstrip patch antenna

IV. MODIFICATION THE STRUCTURE OF A SINGLE ELEMENT MICROSTRIP PATCH ANTENNA TO REDUCE RETERN LOSS AND BETTER GAIN

Here some structural modifications are brought to get better performance of the single element patch.

A. USING A SINGLE VERTICAL SLOT IN DIFFERNT POSITION

Single slot of 0.5mm width and 1.2 mm length is used in different position of a patch to test its performances. In this design simulation are performed considering the slot in left, middle and right side of the single element patch which are shown below.

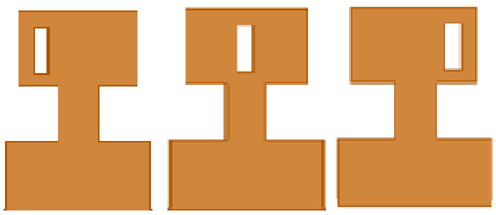

Fig . 4 Modification of a single element microstrip patch antenna using vertical slots in different position (case 1: slot in left; case 2: slot in middle and case 3: slot in right)

The simulated result of these three cases (case 1: slot in left; case 2: slot in middle and case 3: slot in right) are shown graphically in a same graph.

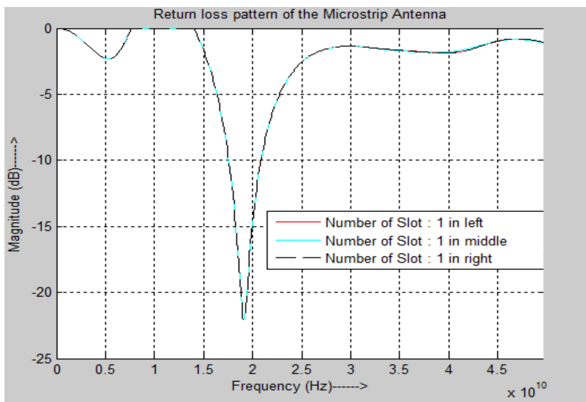

Fig . 5 Return loss a single element microstrip patch antenna using vertical slots in different position (case 1: slot in left; case 2: slot in middle and case 3: slot in right)

TABLE I
COMPARISON OF THE EFFECTS OF CHANGING THE POSITION OF A SINGLE SLOT IN VERTICAL DIRECTION

No of slot	Slot position	Return loss (db)	Operating frequency	Comments
1	Left side of the patch	-22	19.5 GHz	Return loss and operating frequency are independent of the position of a slot in vertical direction
1	Middle of the patch	-22	19.5 GHz	
1	Right side of the patch	-22	19.5 GHz	

From the graphical representation and comparison table it can be conclude that the position of a vertical slot don't affect the performance of the microstrip patch antenna.

B. BY INCRASING THE NUMBER OF VERTICAL SLOT

The number of the vertical slots is increased here to get the lower return loss and higher gain. In this design simulation are performed considering the number of slots one to four which are shown below.

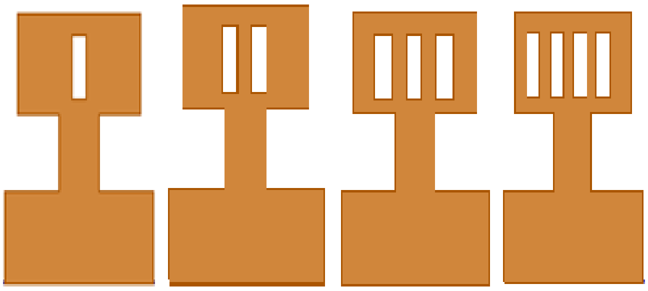

Fig . 6 Modification of a single element microstrip patch antenna by increasing the number of vertical slots.

The simulated result of these four cases (case 1: One slot; case 2: Two slot; case 3: Three slot and case 4: Four slots) are shown graphically in a same graph.

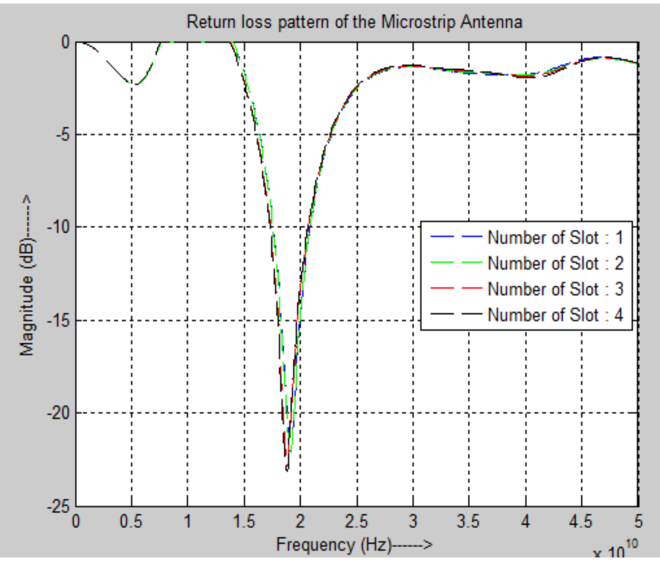

Fig . 7 Return loss of a single element microstrip patch antenna by increasing the number of vertical slots.

TABLE III
COMPARISON OF THE EFFECTS OF INCREASING THE NUMBER OF SLOTS IN VERTICAL DIRECTION

No of slot	Return loss (db)	Operating frequency	Comments
1	-22	19.5 GHz	Operating frequency are independent of the number of a slot in vertical direction but return losses are changed negligibly with increasing the number of slots.
2	-22.5	19.5 GHz	
3	-22.75	19.5 GHz	
4	-23	19.5 GHz	

From the graphical representation and comparison table it can be conclude that operating frequency are independent of the number of a slots in vertical direction but return losses are decreasing negligibly with increasing the number of slots.

V. SERIES FEED MICROSTRIP PATCH ANTENNA DESIGN

Microstrip antennas are used not only as single element but also very popular in arrays. Antenna arrays are used to scan the beam of an antenna system to increase the directivity and perform various other functions which would be difficult with any one single element. Series-feed microstrip array is formed by interconnecting all the elements with high impedance transmission line and feeding the power at the first element. The patch elements are matched together as well as with the transmission line with the quarter wave length transformer method for the maximum power transmission.

In this paper we have designed the four elements rectangular microstrip patch array antenna as shown in Fig. 3, to cover 11.5GHz, 16 GHz and 21 GHz. So this designed antenna is able to meet the demand of X band, Ku band and K band applications.

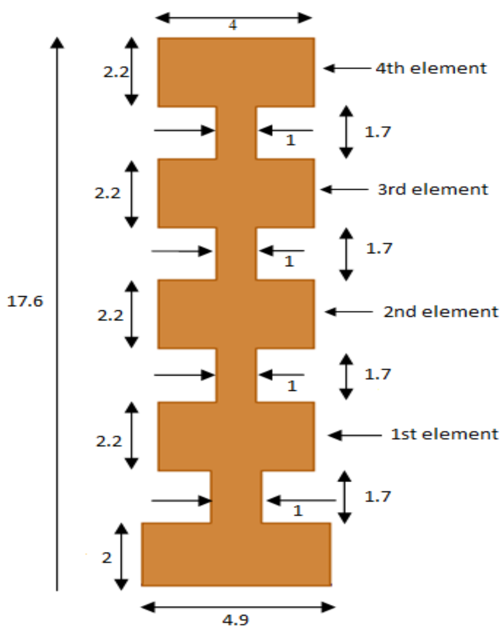

Fig . 8 Four element series feed microstrip patch array antenna

VI. SIMULATION RESULT AND DISCUSSION

The return loss of the proposed microstrip array antenna are simulated in GEMS simulator where the minimum return loss -7.25 db at 11.5 GHz, -17.5 db at 16 GHz and -13.75 db at 21 GHz are found which are shown in Fig.

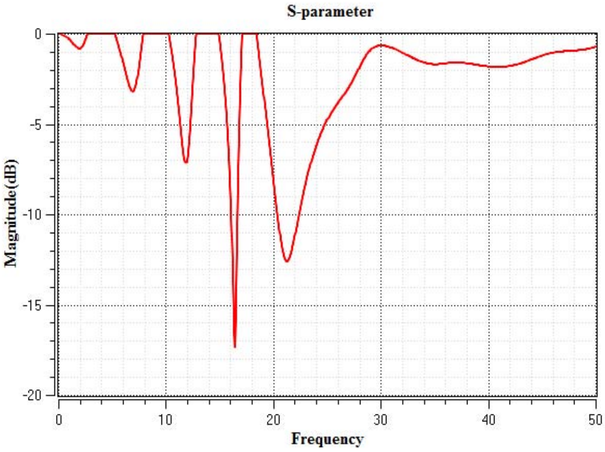

Fig . 9 Return loss of 4-element series feed microstrip patch array antenna (software simulated)

Fig . 10 Practical Four-element series feed microstrip patch array antenna

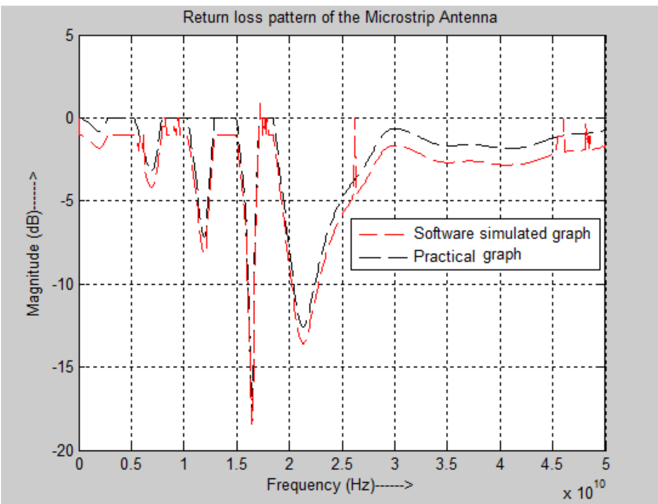

Fig . 11 Return loss of 4-element series feed microstrip patch array antenna (Software simulated and practical result data)

TABLE IIIII

Comparison between single element and series feed microstrip patch antenna array

Para-meter	**Single element patch**			**4-element array**	
	No slot	**Single slot in different posittion in a single element**	**Increaging the number of slot in a single element**	**Simulated**	**Practical**
Return loss (db)	-21	-22	-23(for 4 slots),	-7.25, -17.5, -13.5	-7, -16.5, -12
Operating frequency (GHz)	19.5	19.5	19.5	11.5, 16 and 21	11.5, 16 and 21
Application Band	K band	K band	K band	X ,Ku and K	X ,Ku and K

VII. CONCLUSION

The key features of this antenna is its simplicity in construction and low cost to get improved performance for multi band(X, Ku, and K) applications. Here the designed antenna covers the three bands at 11.5 GHz, 16 GHz and 21 GHz. So this designed antenna is able to meet the demand of X band, Ku band and K band applications. It would be possible to design the bands operating any other system such as in WLAN, WiMAX, EBAN [7] or other wireless systems by changing the dimension of the patch element. It also can be designed to operate the antenna array in ISM band. Here only series feed array configuration has been investigated and in future the corporate feed and corporate-series feed array configuration can be designed and simulated which can be operated at multiple frequencies and having higher directive gain and lower return loss.

References

[1]. John Kraus, Ronald J. Marhefka, *Antennas For All Applications*, Third ed., McGraw Hill 1988

[2]. P.S. Hall, E.lee, C.T.P.Song, Planar Inverted-F Antennas, Chapter 7, "Printed Antenna for wireless Communications" Edited by R. Waterhouse, John Wiley & Sons, Ltd, 2007.

[3]. H.F. Abu Tarbous, H. S. Al-Raweshidy,R.Nalavalan,"Triple Band U-Slot Patch Antenna for WiMaX Mobile Application", 14th Asia-Pacific Conference on Communications,Japan,pp.1-3, 2008

[4]. C. A. Balanis, Antenna Engineering, 2nd ed., Willey, 1982.

[5]. R. Garg, P. Bhartia, I. Bahl, A. Ittipiboon, Microstrip Antenna Design Handbook, Artech House inc., 2001.

[6]. T. A. Millikgan, Modern Antenna Design, 2nd ed. , IEEE Press, John Wiley & Sons inc., 2007.

[7]. Md. Tanvir Ishtaique-ul Huque, Md. Kamal Hosain, Mst. Fateha Samad, Muhammed Samsuddoha Alam , "Design and Simulation of a Low-cost and High Gain Microstrip Patch Antenna Arrays for the X-band Applications", International Conference on Network Communication and Computer (ICNCC 2011), Page no. 548- 552,March 19-20, 2011, India