Adaptive elliptical patch antenna array for WLAN: A Smart approach to beam switching through phase shifting in feed network using elliptical patch array for Dual Band

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Abstract. The WLAN is operated in some high traffic area where the radiation beam produced by the elliptical patch antenna is to be utilized with optimum efficiency. The aim of the antenna array is to produce some directive and switched beams rather than producing omni-directional pattern which cover 360°, can be considered to be wastage in some non-used or low traffic areas. Hence, directive beam and switching it without actually changing the direction of the elliptical patch array is a smart way for WLAN application . A smart antenna array system performs the adaptive beam forming by focusing the beam in the desired direction and creating nulls in other directions to avoid the interference and the wasting of the beams. This is performed by the operating the phase shifting in its feed network and different ports. This paper investigates the performance of the elliptical patch array patterns operating in dual bands with different phase shifting for the optimum performance of the WLAN applications.

Keywords: Beam forming, array, adaptive antenna, WLAN, elliptical patch.

I. INTRODUCTION

In this era of high evolution in communication technology, the WLAN has become intensively popular for the various purposes such as personal area networking, the high speed internet, the video streaming, multimedia and so on. For the dramatic change of the demand of wireless access in the indoor environment, WLAN has become a big issue considering its performance and efficiency. Therefore, to ensure the high data rate and the effective use of the network, the compensation of the multipath effects and the co-channel interference have grown to be a matter of great interest. In addition, the high gain and the high coverage of the WLAN to a desired direction of high traffic with reducing the dead spot in an indoor environment also became a high priority for the researchers.

In earlier version of WLAN, the simple dipole antenna is used which exhibits Omni-directional pattern which means the signal is scattered to all direction with low gain and efficiency and hence the users with high quality signal achieve the small percentage of the signal compared to their demand while the signal is wasted in other areas with low demand. Even boosting the radiation of this antenna, the performance cannot be improved, as the signal being boosted to all directions.

The smart antenna array enhances the radiation efficiency by producing the distributed current throughout the whole area. This distributed current produces the directive beams and narrow or pencil beam and those directive beams can be switched towards the desired direction by using the phase shifting technique in its feed network (Balanis, 1997).

In this paper, the elliptical patch antenna array is designed with typical micro-strip patch antenna for its compactness and simplicity as the research aims at the compact and low cost design for the WLAN application (Balanis, 1997). Considering the array, the multiple elements can be mounted on the same plane which increases the compactness in terms of thickness of the antenna system for the WLAN. This design does not require any LINC (Linear amplifications with Non-linear Components) Power Amplifier, hence, no risk of imbalance of the gain when practically implemented (Lee & Ng, 2005) Due to simple feed network even with increasing elements, this design is not limited to a 4X4 Butler matrix (Pham, Lee, & Flaviis, undated) . In this work a simple planar array which exhibits a wide range of switching options and that eliminates the requirement of a complicated network such as a hexagonal 7 element array (Akkermans & Herben ,2007).

II. WIRELESS LAN

The whole WLAN topology can be divided into two basic parts: the AP and the clients. The access point act as the radio transceiver between the other devices those are enabled with WLAN. The AP can be compared with the base station (BS) of a cellular network which is the radio interface for the whole network (Alvarion website 2009). The clients can be exemplified as the desktops, work stations, PDA, IP phones, and so on.

The IEEE 820.11 standard which includes the WLAN communication is set to be operated at 2.4, 3.6 and 5 GHz frequency. In this paper, the design frequency was selected as 3.6 GHz and 5 GHz which is used by the IEEE 802.11b (Vershney,2003). In WLAN system, the smart antenna array can be implemented as the adaptive antenna having switched beam system. The array of the patch antenna is considered as the four element array with different alignments and feed networking to operate in different phases. The feed network provides the directive beam after the phase is adjusted at different ports. Along with the changing of the phase and amplitude, the pattern, orientation of the elements can be adjusted to investigate the produced directive beam and switching of those beams. The side lobe associated with the main lobe is distributed according the priority of the traffic demand.

III. FUNDAMENTALS OF ANTENNA ARRAY

To achieve the desired directional radiation pattern, multiple radiating elements are needed to be configured providing interconnection between the elements. This arrangement is defined as array antenna, simply, an array. Same level of performance of a single large antenna can be maintained by producing an array of many small antennas with the advantage of directivity and electronic scanning of the main beam.

According to geometrical configuration basically two types of array are found - the linear array and the planar array. Additionally, phased array can be formed by introducing phase shift to the exciting current of each element of any array. This array is capable of scanning into space (Alvarion website 2009).

IV. THE BEAM SWITCHING CONCEPTS FOR LINEAR ARRAY

For the case of n-element linear array, if the relative phase excitation angle between the array elements is defined as α and the desired angle of the main beam switched to is θ, then,

$$\alpha = -kdn\cos\theta \qquad (1)$$

Where k is the wave number = $2\Pi/\lambda$, d= inter element distance and n= total number of elements.

Exerting the arbitrary value of α, one can get the desired direction of the main beam of the considered array.

Additionally, if the number of array (n) increased, the number of side lobes increase. The width of the side lobe and main lobe can be measured by the following formulae (Rahman & Dey, 2013) .

$$\text{Width of the main lobe} = 4\Pi/n$$

$$\text{Width of side lobe} = 2\Pi/n$$

The above equations demonstrate the width of the lobes increased with decreasing of the number of element and this has got greater impact on the main lobe rather than side lobe.

V. THE BEAM SWITCHING CONCEPTS FOR LINEAR ARRAY

A. Designing the single element

The designed band to operate the WLAN is 3.6 GHz and 5 GHz (for IEEE 802.11b). A quarter wavelength section is included for impedance matching between the feeding and the patch. The dimension is nearly $\lambda_{eff}/4$, where λ_{eff}=free space wavelength/ √(dielectric constant)125(mm)/√4.3 which produces effective wavelength of 60 mm. Hence we determine the length of the quarter wavelength section as 15mm. The width of the quarter wavelength section is approximately 0.65 mm.

The dimension of the patch is selected nearly as 9.5 X 34.7 mm. The height of the patch, quarter wavelength section, substrate and the feed is 1.5 mm. But, the height of ground is 0.1 mm. The substrate used for the designed antenna FR-4 (loss free) with dielectric constant of 4.3.

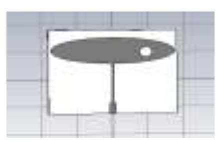


Fig.1 Single elliptical patch antenna

B. Designing the Linear Array

The first approach is to make the linear array with four elements at the equal patch center-center distance of 80 mm ($\lambda_{eff}/4$ <distance < $\lambda_{eff}/2$,) by providing the feeds individually with the same ground plane and substrate (Figure 2and Figure 3). All the single elements are fed with different phase of current and the beam switching is observed.

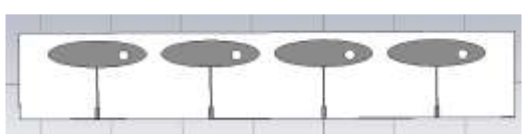
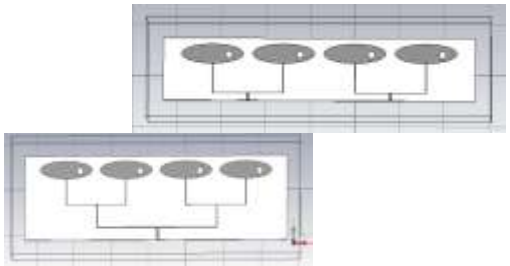


Fig.2 Linear Elliptical Array with Individual Feeds

The same array is fed with two feeds and hence two branch feeds are included with two feeds (fig. 3(a)).

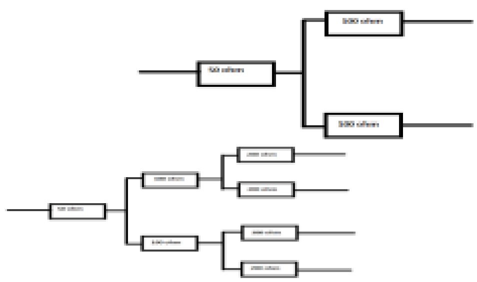


(a)

(b)

Fig. 3 The Linear Array with (a) Two Feeds and (b) Single Feed

To match the 50 ohms main feed, the extended two branches of feed have to be 100 ohms (parallel of 50 ohms) before it connects to the quarter wavelength section. The width of 100ohms line width is changed to exhibit matched impedance. The widths of the branch feeds are set to 0.6785mm to produce 100 ohms impedance. In this case, the two feeds are given different phase shift. Lastly, the four elements linear array with single feed is designed. The impedance is matched with the corporate feeding network which follows the simple parallel resistance rules (Fig. 4(b)).



(a)

(b)

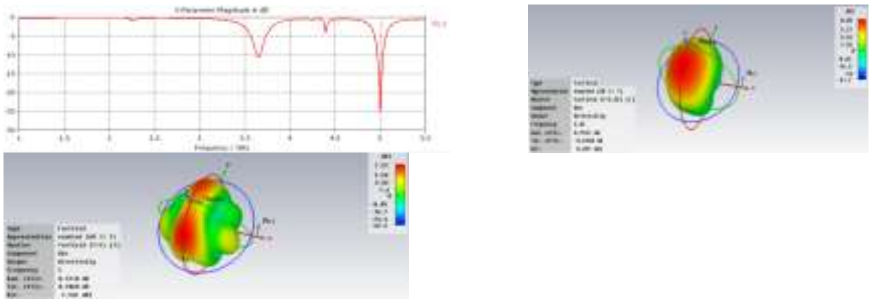
Fig. 4 The impedance Matching of the Branch Feeding of (a) Two Feeds and (b) Single Feed

The widths of further extended branches which are having impedance of 200 ohms were set to .0456 mm and hence are connected to quarter wavelength sections.

VI. Results and Discussion

A. The Single Element

Fig.5a shows the dual band with all the dimensions described in methodology. The reflection coefficient is found as -10.749 dB at the resonant frequency of 3.6562 GHz and the reflection coefficient is found as -25.094 dB at the resonant frequency of 5.0071 GHz .



(a) (b)
(c)

Fig. 5 The single element (a) reflection coefficient and (b) radiation pattern for 3.65 GHz (c) radiation pattern for 5 GHz

B. Linear Array with Individual Feeds

B.1 THE S-PARAMETERS

The S-parameters diagram are shown below where at the resonant frequency of 3.6461 GHz and 5.1311 GHz, the antenna exhibits reflection coefficients of -9.7389 dB and -14.574 dB.

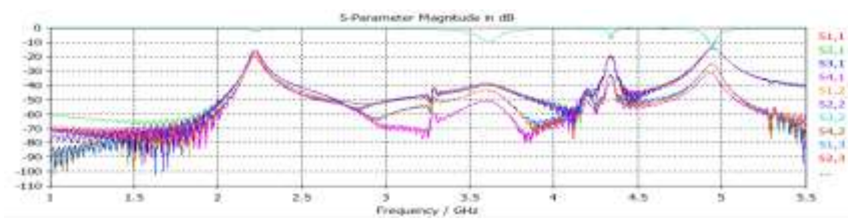
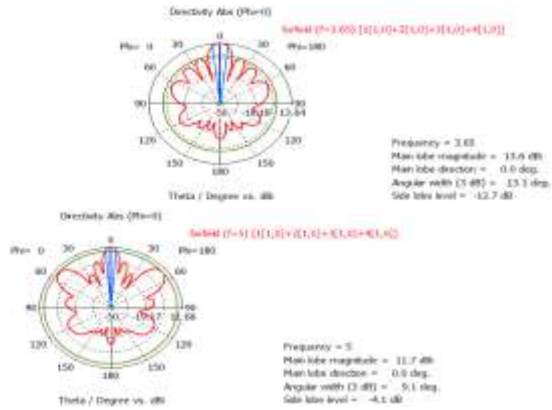


Fig. 6 The S-Parameters for Linear Array with Individual Feeds

B.2 FORMATION OF SWITCHED BEAM

At the very beginning, no phase shift is introduced, which gives the narrow beam along zero degree along with some side lobs as from the equation (1). Here, the inter element distance d is 80 mm and k=wave number, n=number of elements.

Here, as the switched beam angle is 0 degree, which means, the phase difference α is zero. As the phase and amplitude is equal, there is the directive beam along the bore sight angle where there are nulls in all other direction. So, for excitation, the first port is assumed as the left most and that is continued to the rightmost which is the fourth port.

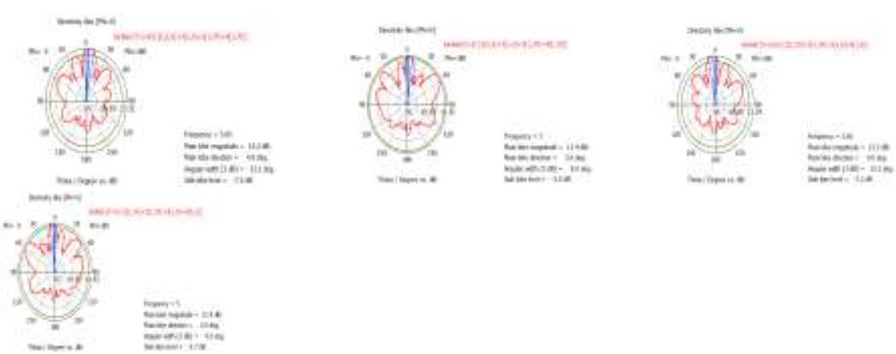


(a) (b)

Fig. 7 The Beam Pattern for α=0 for Linear Individual Feed Array (a) α=0 for 3.65 GHz (b) α=0 for 5 GHz

Keeping the first two ports at as reference (0 degree), the other ports were excited with the same phase of 70 degree. So, here, the relative phase shift from 1st pair of patches to 2nd pair is 70. This gives the array main lobe direction towards 4 (θ) degrees (figure 8a and figure 8b). Beside the 13.2 dBi main beam, the -7.2 dB side lobe is produced.

The main beam can be switched towards 4 degree left to the bore sight angle as shown in (fig. 8(c) and fig8(d)). Here, all four patches have reversed phase shift with respect to first case. As the relative phase shift α is inverted ,the beam angle θ must be changed to another side of zero axis which caused the beam to be switched from previous position. The rotation is shown below (fig. 8):

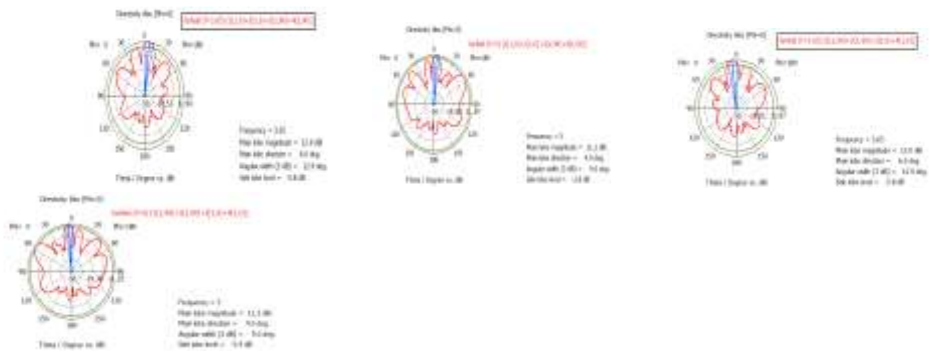


(a) (b) (c)
(d)

Fig.8 The Beam Patterns for 0,0,70,70 (for 3.65GHz (a) and for 5GHz (b)) and 70,70,0,0 (for 3.65GHz (c) and for 5GHz (d)) for Linear Individual Feed Array

The width of the main lobe is 4Π/N. Here, N = 4 (four elements). So, width is 9 degree (in decibel) after calculation whereas for minor or side lobe width is 2Π/N. Hence, the side lobe width is 1.5708 degree.

In the similar way after changing the phase shift 0 to 90 degrees compared to either consecutive pair of patches a 6 degree switching of the main beam for linear patch array about the bore sight angle can be made (fig. 9).



(a) (b) (c)
(d)

Fig. 9 The Beam Patterns for 0,0,90,90 (for 3.65GHz (a) and for 5GHz (b)) and 90,90,0,0 (for 3.65GHz (c) and for 5GHz (d)) for Linear Individual Feed Array

The switched beam angle θ is shifted to either side by changing the phase shift angle α (0-0-90-90 to 90-90-0-0). So, for a four elements linear array, with individual feeds, keeping one pair as reference and excitingly the adjacent pair of the patches with the same angle the main beam can be switched randomly to either side of bore sight angle.

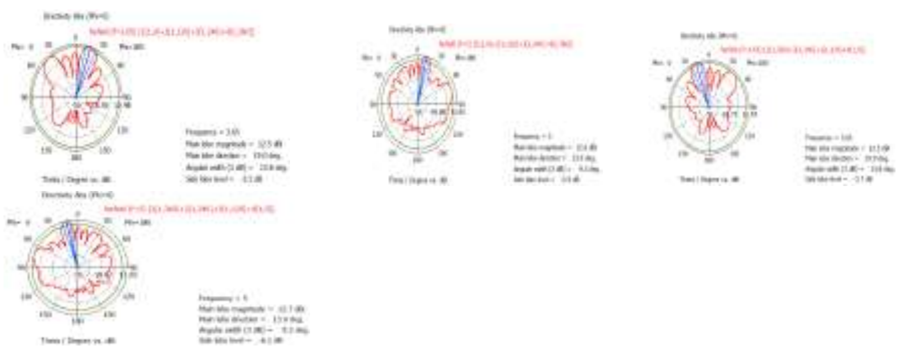
Furthermore, exciting the feeds in an increasing order with same difference we get the following patterns. For example, having the consecutive phase of 0, 90, 180 and 270 degrees at four consecutive feeds, the beam switches 10 degrees from its position (fig. 10). If the orders of the phase excitation are reversed, the beam can be shifted to other side of bore sight angle to same degree. It means, we can get an overall switch of 20 degrees of the main lobe by just exciting the feeds with α=90 degrees apart and making the phase shifting in different ports in reverse order.

(a) (b) (c)

(d)

Fig.10 The Beam Patterns for 0,90,270,180 (for 3.65GHz (a) and for 5GHz (b)) and 180,270,90,0 (for 3.65GHz (c) and for 5GHz (d)) for Linear Individual Feed Array

If we increase the α, the θ will be increased as well that means the overall switching can be increased as shown below (fig. 11). The relative phase angle is set 120 degree (0,120, 240, 360/0), which produces a 19 degree directive beam and inversely, setting the as 360, 240, 120, 0 (α) produces the beam shifted to 19 degrees to the left of bore sight angle. So, the overall shifting of the beam is 38 degrees.



(a) (b) (c)

(d)

Fig. 11 10 The Beam Patterns for 0,120,240,360 (for 3.65GHz (a) and for 5GHz (b)) and 360,240,120,0 (for 3.65GHz (c) and for 5GHz (d)) for Linear Individual Feed Array

C. **The Linear Array with two feeds**

C.1 **S-PARAMETERS**

This array gives more reflections to the current and hence causes to be degraded as it propagates. The return loss not improved compared the individual feed array which is -9.6498 dB at the resonant frequency of 3.6434 GHz and -14.506 dB at the resonant frequency of 5.1302 GHz.

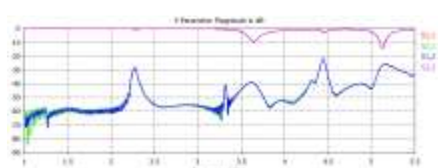
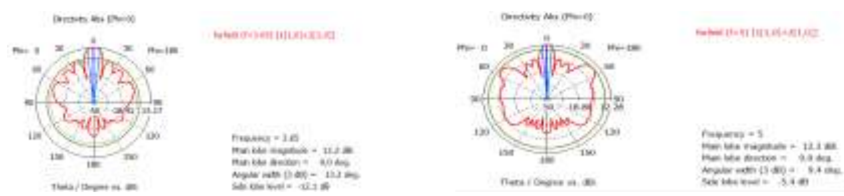


Fig. 12 The S-Parameter for Linear Array with Two feeds

C.2 **FORMATION OF SWITCHED BEAM**

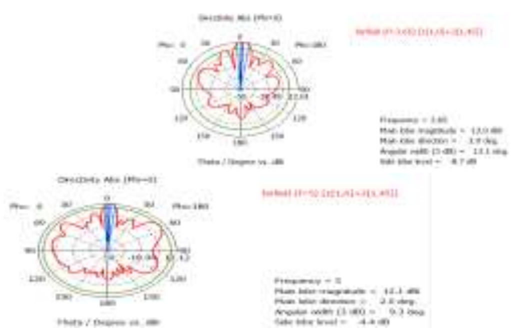
At first, the two ports are excited with similar angle (here α = zero) as before. So, the beam will be along bore sight angle with the maximum amplitude (13.2 dBi) (fig. 13). The null occurs at 30 degrees with a side lobe level of -12.1 dB. This side lobe appears for the individual element pattern with different phase shifting.



(a) (b)

Fig. 13 The Beam Pattern for α=0 (a) for 3.65 GHz (b) for 5 GHz for Linear Two Feeds Array

For the case of phase excitation of 45 degrees, the main lobe becomes directive to 3 degrees (fig. 14a) and 2 degrees (fig. 14b). If we change the phase excitation= -45, the direction of the beam can set to other side of the 0 degree angle axis with same angle.



(a) (b)

Fig. 14 The Beam Pattern for 0,45 (α=45) (a) for 3.65 GHz (b) for 5 GHz for Linear Two Feeds Array

After an increment of relative phase excitation (180 degrees), the pattern below (fig. 15a) is found which exhibits the directive beam towards to 11 degrees with a lower level of 10.6 dBi and a minor lobe of -7.7 dB and 8 degrees with a lower level of 9.4 dBi and a minor lobe of -2.4dB.

(a) (b)

Fig.15 The Beam Pattern for 0,180 (α=180) (a) for 3.65 GHz (b) for 5 GHz for Linear Two Feeds Array

The associated side lobe tends to be increasing with a null at 0 degree. The phase difference of 180 degrees causes a null at the bore side angle which means the phase of current meets destructively at the bore sight angle. Any phase shift of 180 degrees will produce the same pattern for this array.

C.3 **A COMPARISON WITH THE PREVIOUS RESULT OF ARRAY WITH INDIVIDUAL FEED**

A closer look to the previous array pattern (Fig. 9a ,9b) with individual feed with the phase excitation angle 0 degree at the first pair of patches and 90 degrees to the next pair, reveals almost the same pattern as the following (Fig.16a) where the beam angles are 6 degree and (Fig.16b) where the beam angles are 4 degree . This is because of the same excitation angle is being exerted to different elements. The each branch feed for each couple of patches for the two feed array is producing a phase difference of 90 degrees in current for each pair which is equivalent to create the phase excitation angle as 0, 0, 90 and 90 in the case of previously discussed individual feed array.

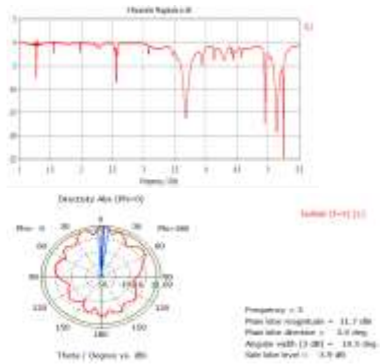
(a) (b)

Fig. 16 The Beam Pattern for 0,90 (α=90) (a) for 3.65 GHz (b) for 5 GHz for Linear Two Feeds Array

D. **The Linear Array with Single Feed**

D.1 **S-PARAMETERS**

The single feed linear array shows the return loss -16.384 dB at a resonant frequency of 3.6761 GHz . There is also a interesting development in the 5 GHz range . There is a return loss of -19.277 dB at a resonance frequency of 5.1399 GHz and return loss of -17.593 dB at a resonance frequency of 4.947 GHz and return loss of -23.912dB at a resonance frequency of 5.2448 GHz. So, three new bands in the 5 GHz have been found Fig (17a).



(a) (b) (c)

Fig.17 (a) S-Parameter and (b)Beam Pattern for Linear Array with Single Feed

For single feed, there is only one port; hence, it is not possible to change the relative phase excitation angle(α). For α being zero, the resultant beam will not be steered rather it will remain in the zero angle(figure 17b , 17c).

A side lobe level of -11.5 dB for 3.65 GHz and -3.9 dB for 5 GHz is due to some mutual coupling of current between the elements.

D.2 COMPARISON WITH INDIVIDUAL FEEDS

However, comparing with the pattern for individual feed linear array (Fig. 7) with zero degree relative phase excitation, we get the same pattern as above (figure 17b,17c). Similarly, introducing the α = zero at the first pair and 90 degrees to other pair, the beam can be directed towards 6 degrees(3.65 GHz) and 4 degrees(5 GHz) left to the main beam angle (0) (Fig. 9) which means, if we keep a single port and want to obtain the same result, later pair of the patches of the array must be provided with 90 degree relative phase angle of current relative to the first pair. Referring to figure 10, to make a directive beam of 20 degree angle, the patches of single feed array must be provided with gradually increasing of 90 degrees phase angle (0, 90, 180 and 270) to each patch.

CONCLUSION

In this paper, the linear elliptical patch arrays are designed and the performance is investigated with different feeding network. The relative phase shifting at different ports produces the directive beam towards the desired direction with the main lobe while some side lobes are also associated, which is the common phenomenon of an array system. However, the according to the demand and traffic concentration in the indoor environment, the side lobes and main lobe can be distributed on the basis of their strength rather than wasting them. Beside the main lobes, the side lobe can be focused to less number of users with less demand.

Typical Omni-directional antenna exhibits good coverage, large bandwidth which is not the essential feature for WLAN systems. Larger bandwidth and whole area sometimes cause the interference from neighboring WLANs and the signal can be received by some unwanted third party which affects the security system. The designed smart antenna array is the possible solution to avoid security breach, waste of bandwidth and some radio wave propagation constraints. The linear array is simpler to configure and the inter element distance between them is easily reconfigurable. Additionally, the feed network used in the paper is simple to design and can withstand even in the case of increasing number of elements.

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