X-Polarization Array Antenna with Parallel Feeding for WiMAX 3.55 GHz Application

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Abstract— **An X-Polarization array microstrip patch antenna for WiMAX application is introduced in this paper. The array antenna operates at WiMAX frequency of 3.55 GHz. The substrate used is FR-4 with the thickness of 1.6 mm, relative permittivity of 4.5 and loss tangent of 0.019. The antenna use parallel feeding network to feed all the eight elements with coaxial port. The array has gain of 6 dBi, and directivity 8.754 dBi. The array antenna only requires single input port unlike conventional X-Polarization array antenna that uses multiple input port application. Parametric study of cross angle to antenna performance is studied which have not been discussed in the past research and coupling between the elements in the array is presented.**

Keywords- X-Polarization, Coupling, Cross Angle, radiation Pattern

I. INTRODUCTION

In Non Line-Of-Sight (NLOS), the signal which is transmitted through wireless link from the transmitting antenna encounter various obstacles, resulting in reflection and scattering of waves through different path to the receiver. The multiple version of transmitted signals have different characteristics than the direct signal due to the possibility of the reflected signal to have time delay, phase shift, distortion and polarization mismatch. The reflected signal will be combined with the direct signal causing destruction interference at the receiver. The interference result into poor reception of signal by the receiving antenna. The process that creates these multiple copies of transmitted signal is called multipath propagation[1]. Antenna performance is one of the important criteria that determine good transmission and received signal. There are many ways that can be used to improve antenna performance. Antenna diversity is one of the ways that can improve the signal transmission in wireless link. One of the antenna diversity is the polarization diversity. Polarization diversity joins antenna pairs with orthogonal polarization.

A lot of researches have been done on antenna diversity but little has been done on X-polarization diversity antenna. In the extent of our knowledge, X-Polarization diversity antenna is not yet designed for WiMAX application at operating frequency of 3.55 GHz. The design only requires one port unlike in most of the previous research in X-polarization and the rest of the paper that studied on dual linear slant polarization. Only one port is required in the proposed design thus there were no isolation issues that need to be taken care of unlike in the typical multiport application or design. In this paper also provide studies on the effect of the cross angle α and coupling between the array elements.

Polarization diversity is preferred than space diversity due to faster installation, cheaper and overall structure consume less space[2]. In this paper a wide band antenna covering 3G, Digital Cellular Standard (DCS) and Personal Communication Service (PCS) band have been designed. However the antenna is not low profile.

According to [3] dual linear slant polarization is essential for application at the base station. They achieved significant isolation level between the two polarizations which are as low as 30 dB. The design use a director, reflector and a cross slot with the radiating patches. The antenna structure is rather complex. Polarization diversity is suitable to be implemented in antenna for MIMO environments.

X-Polarization diversity is a type of polarization diversity. Very few numbers of researches has been done on the design and analysis of X-Polarization diversity antenna. In [4], numbers of antenna design using dual polarization have been designed and studied including 1x4 elements array antenna using X-polarization for WLAN application. X-polarization antenna have difficulty in achieving good gain due to mutual coupling[5]. Mutual Coupling in X-polarization diversity system has been studied. In this paper Mutual coupling (MC) between elements in array antenna is generally undesirable for antenna operation. In X-polarization antenna, MC might influence the directivity and gain of the antenna. Mathematical modeling has been derived for mutual coupling in array antenna. It has been shown that MC increase as the β and η is increased. The effect of cross angle to MC has been studied but it does not discuss on the effect of cross angle to the antenna performance which are directivity, gain, radiation pattern and efficiency.

There are number of papers that design antenna based on dual linear slant polarization. Novel dual polarized antenna has been designed using proximity coupled feeding [6]. It achieves high isolation and low cross polarizations through the use of corner fed which have two input feeding or port. Dual linear slant 45^{o} polarization is extensively implemented at the base station to combat multipath propagation effects. It is suitable to be used for the network of base station to mobile station that is highly involves in multipath environment. It is also interesting, from [7], where the circularly polarized antenna is use to construct dual linear slant 45° polarization and for wideband application from 1.7GHz to 2.7GHz. However, four antennas are required along with 2 main input ports.

In [8], dual port annular sector radiating line antenna (ANSERLIN) have been designed to realize dual linear 45° polarization, achieving wider radiation bandwidth of 35% with the use of four elements array for Personal Communication Network (PCN) via Universal Mobile Telephone System (UMTS) bands, from 1.7GHZ to 2.2GHz with the use of simultaneous excitation of two input ports and have the ability of beam tilting by physical rotation. However, proper arrangement is needed to realize slant 45° linear polarizations.

II. ANTENNA DESIGN

Figure 1 shows the geometry of the array antenna. The substrate dimensions is 135mm x 135mm.The design uses inexpensive FR-4 substrate with the thickness of 1.6mm, relative permittivity 4.2 and loss tangent of 0.019. Copper thickness is 0.035mm.The patch is connected to feeding network through inset fed. The patch dimension is 21.58mm x 20.75mm (width x length) with d as the distance between the elements. The input port via coaxial is connected to first quarter wave matching line, f_0 of width 1.51mm. The first transmission line f_0 connected to input port is designed to have width that is slightly bigger width than the core of the coaxial which is 1mm. The antenna design is shown with eight radiating element label 1 to 8 respectively. Table I shows the feeding network dimensions of the antenna.

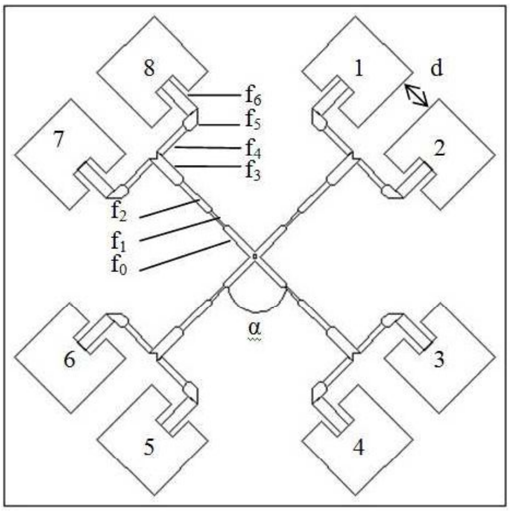


Figure 1. Geometry of X-Polarization array antenna

Antenna was designed using CST microwave studio 2010. Antenna dimension calculations are based on equation (1)-(7). V_0 in equation (2) is speed of light in vacuum. Equation (7) is the calculation for inset feed length, y_0 and this equation is only true for $2 \leq \varepsilon_r \leq 10$ [9]. y_0 for the antenna is 6 mm.

$$\lambda_{eff} = \frac{c}{f_r\sqrt{\varepsilon_{reff}}} \tag{1}$$

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

$$\varepsilon_{reff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left(1+12\frac{h}{w}\right)^{-1/2} \tag{3}$$

$$\frac{\Delta L}{h} = \frac{(\varepsilon_{reff}+0.3)(\frac{w}{h}+0.264)}{(\varepsilon_{reff}-0.258)(\frac{w}{h}+0.8)} \tag{4}$$

$$L = \frac{1}{2f_r(\sqrt{\mu_o\varepsilon_o}\sqrt{\varepsilon_{reff}}} \tag{5}$$

$$L_e = L + 2\Delta L \tag{6}$$

$$y_o = \frac{L}{2}10^{-4}\left\{\begin{matrix} 0.001699\varepsilon_r^{7} \\ +0.13761\varepsilon_r^{6} \\ -6.1783\varepsilon_r^{5} \\ +93.187\varepsilon_r^{4} - 682.69\varepsilon_r^{3} \\ +2561.9\varepsilon_r^{2} - 4043\varepsilon_r + 6697 \end{matrix}\right\} \tag{7}$$

$$\text{Percent bandwidth (\%BW)} = \frac{f_2-f_1}{f_c} \text{ x } 100\% \tag{8}$$

$$Z_{QWT} = \sqrt{ZoZ_1} \tag{9}$$

TABLE I. FEEDING NETWORK DIMENSION

Antenna dimension	Length (mm)	Width (mm)
f_o	11.65	1.51
f_1	5.29	0.57
f_2	11.01	1.51
f_3	10.69	3.09
f_4	9.76	1.62
f_5	6.00	3.09
f_6	10.84	3.09

this design, the array antenna is fed from one 50Ω coaxial port, and then parallel feeding network is used to equally divide the power to the 8 elements. The matching technique used is quarter wave transformer impedance matching as in equation (9). The length of the quarter wave impedance matching is $\frac{\lambda_{eff}}{4}$ which is approximately 10.61mm. The first quarter wave impedance matching in this design is f_0. At the input port, the concept of Kirchhoff's circuit law was implemented, whereby total amount of input current is equally distributed to the four transmission line,f_0 regardless of the impedance provided that its having equal value of impedance.

However, the width of f_0 was set to 1.51mm, suitable with the fabrication constraint. Hole for the coaxial port has to be drilled perfectly at the centre due to the symmetric structure of array. The drilling has to be carefully done so as not to damage the first transmission line.

III. RESULTS AND DISCUSSION

Parametric studies have been done to observe the effect of the cross angle, α to the antenna performance. α is the cross angle between the array element as shown in Figure 1.The parametric study has been done for three different values of α which are 80°, 90° and 100°. From Figure 2, we can see that different value of α other than 90° can cause the resonant frequency to be shifted. The S_{11} parameter curve for cross angle 80° and 100° gives the same characteristics and it has been shown that the resonant frequency shifted to left at 3.28 GHz. Regardless of larger or smaller cross angle than 90° the resonant frequency of antenna will be shifted to the left but the shape of return loss curve remain the same. It is also observed from Figure 3, cross angle gives effect on the radiation pattern of the antenna. If the cross angle is set to 90° the main beam is correctly at θ = 0°. Any cross angle other than 90° would cause the main beam diminish at θ = 0° and resulting in two main side lobes with lower gain which is shown to be 2.086 dBi and 2.778dBi for cross angle of 80° and 100° respectively. The two main side were located at θ = 25° and θ = -25°. Hence, different values of α other than 90° significantly influence the antenna performance. The antenna total efficiency is also abruptly degraded to 0.03% with different cross angle other than 90°.

Cross angle other than 90° produce the non symmetrical design of array antenna. This non-symmetrical structure cause the element pair such as pair of element 1 and 2 to be closer distance with pair of element 3 and 4, hence increasing the effect of mutual coupling between the element pair. Summary of the parametric study is shown in Table II. Cross angle of 90° gives symmetrical design of the array antenna and uniform distance of element pair with another pair.

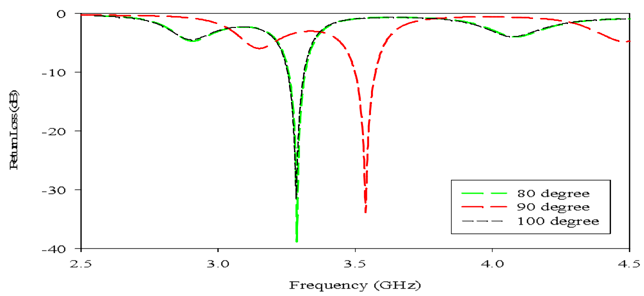


Figure2. Variation of return loss with respect to different cross angle

The simulation result is compared with measured. The simulated and measured return loss is shown in Figure 4 where the resonance frequency is at 3.55 GHz. The simulated return loss is -33.89 dB and percentage bandwidth of 2.04%. The measured result shows the resonant frequency is shifted from 3.55 GHz to 3.54 GHz. The measured return loss at 3.55 GHz is -11dB. The measurement result shows a good agreement with simulated result.

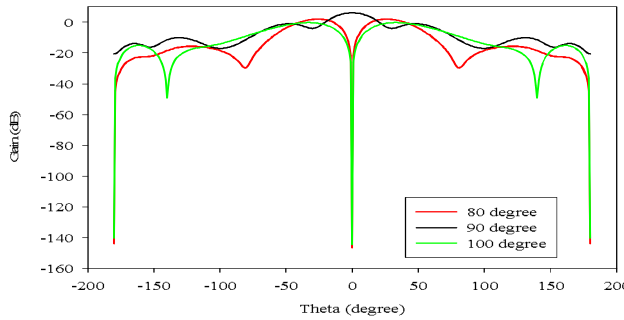


Figure 3. Variation of radiation pattern with different cross angle

TABLE II. VARIATION OF ANTENNA PERFORMANCE WITH RESPECT OF DIFFERENT CROSS ANGLE

Cross angle, α (degree)	**80°**	**90°**	**100°**
Gain (dBi)	2.086	6.083	2.778
Directivity (dBi)	9.482	8.754	10.21
Efficiency (%)	0.03	53.41	0.03

Figure 5(a) shows 3D plot and 5(b) shows the polar plot of the radiation pattern of the antenna with gain of 6.083 dBi in the main lobe direction. The polar plot is based on main lobe alignment. Side lobe level is -7.1dBi with angular width of 29.1 dB. The antenna simulated performance is shown in Table III.

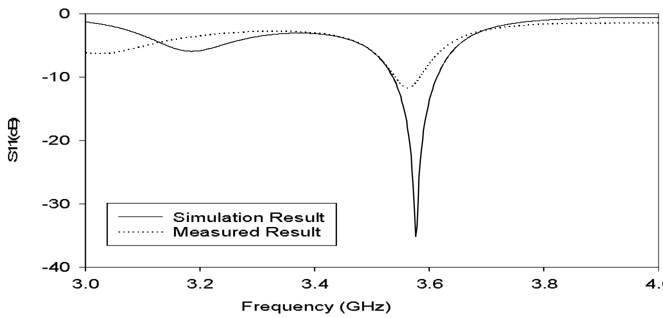
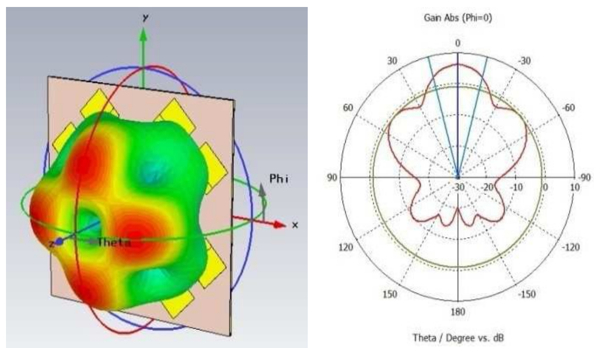


Figure4. Return loss result



(a) (b)

Figure 5. (a) 3D and 5(b) polar plot for radiation pattern at 3.55 GHz

TABLE III. ANTENNA PERFORMANCE

Antenna Parameter	Result
Return loss S11 (dB)	-33.89
Gain (dBi)	6.083
Percentage Bandwidth (%BW)	2.04
Half Power Beamwidth (degree)	29.1

The coupling between the elements in the array structure is also studied. Due to the symmetrical properties of the array structure, the coupling studies were done only on element 1 to 4. The simulation studies of 4 radiating element is sufficed to sight overall coupling between the elements. By applying discrete port to each of the elements enable the coupling between elements of the array to be studied. Figure 6 shows the simulated coupling between elements. S_{31} and S_{42} pair, S_{13} and S_{24} pair, and S_{23} and S_{14} pair exhibit same curve characteristics respectively. Additionally, S_{21}, S_{12}, S_{43}, and S_{34} exhibit the same curve characteristics too. Hence, only S parameter curve for S_{31}, S_{13}, S_{23}, S_{21}, S_{41}, and S_{32} has been shown for simplicity The S parameter pair that have the same curve characteristics also have the same value at any given frequency range of our studies.

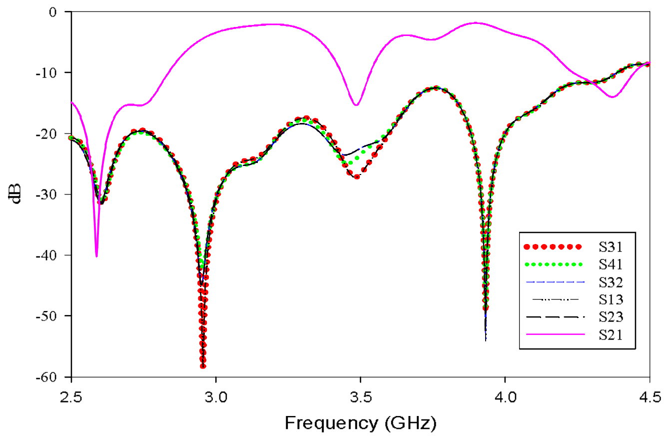
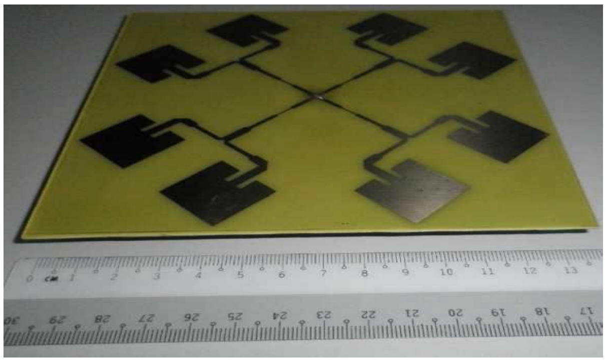


Figure6. Coupling in the antenna element 1, 2, 3 and 4.

S_{31}, S_{13}, S_{23}, S_{21}, S_{41}, and S_{32} are -23.37dB, -23.37 dB, -21.53, -8.31 dB, -21.54 dB and -21.53 respectively at 3.55GHz. This shows coupling is considerably low for non pair element. In contrast for pair element such as element 1 and element 2, the coupling is high for instance S_{21} is -8.31 dB.

Low coupling is due to the larger distance between them that is greater than λ_{eff} which gives insignificant effect of coupling between antenna elements. Element pair have strong coupling due to shorter distance between them. High coupling is due to closer distance between element 1 and 2 and between element 3 and 4 which is d less than $\frac{\lambda_{eff}}{4}$.

Increase the distance between element 1 and 2 or between element 3 and 4 will decrease the distance between element 2 and 3 and vice versa. Increase the distance between elements will reduce the coupling effect and vice versa. However, if distance is increased between element 1 and 2, coupling between element 2 and 3 will increase. Distance between element need to be optimized to attain minimum coupling between elements. The fabricated antenna is shown in Figure 7.



IV. CONCLUSIONS

In this paper, X-polarization antenna has been designed for patch antenna that is slanting at an angle of either 45° and -45° for WiMAX frequency at 3.55 GHz. The Array antenna has gain of 6dBi and is suitable for application of communication between base stations with mobile station. Being a dual linear slant polarization, this antenna is suitable for environment that is highly disturbed by the multipath propagation effect. Furthermore, by using polarization diversity compared to space diversity, space constraint and cost is improved.

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