Gain Enhancement of Octagon Microstrip Yagi Antenna Utilizing 1-D Photonic Crystal (PCs) Cover

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Abstract— **A high gain Octagon Microstrip Yagi Antenna (OMYA) for Worldwide Interoperability for Microwave Access (WiMAX) application at unlicensed frequency of 5.8 GHz is presented in this paper. The proposed antenna was simulated and optimized using full-wave EM simulator. The simulated results show that the gain of the proposed antenna at frequency of 5.8 GHz is 13.45 dB with S_{11} of -32.57 dB. Hence, an extra gain of about 5.47 dB can be obtained through this design.**

Keywords—high gain, microstrip Yagi antenna, superstrate layer, ISM Band Frequency

I. Introduction

WiMAX which stands for Wireless Interoperability for Microwave Access is one of the newest broadband wireless technologies around today. WiMAX can operates using licensed or unlicensed band frequencies and 5.8 GHz is one of unlicensed ISM (Industrial, Scientific and Medical) band frequencies which can be used for WiMAX application [1]. This technology is deployed to enable connectivity across a large area which is based on IEEE 802.16. Thus, WiMAX has an incredible interest in high gain antennas.

Antenna is one crucial part on WiMAX system. There are a number of types of antennas, and micro-strip antenna is one popular antenna in wireless systems. These antennas have some attractive advantages; low profile, easy fabrication and simplicity in design. On the other hand, they also have some drawbacks, and low gain is one major drawbacks usually associated with micro-strip antennas. Nevertheless, it can be tackled by using some methods.

A number of methods have been researched by some researchers throughout the world to improve the gain of micro-strip antennas, for instance, using C-Foam as substrate and applying metamaterial concept as superstrate layer. In addition, there are also some researchers who have researched the combination between Yagi-Uda antenna concept and micro-strip antenna method.

The idea of micro-strip Yagi antenna started from John Huang in 1989. He successfully introduced the Yagi concept for the planar micro-strip. The configuration of his micro-strip Yagi antenna is similar to the conventional Yagi-Uda antenna which consisted of a reflector element, a driven element and two director elements. In 2007, Gerald R. Dejean *et al* designed a new high gain micro-strip Yagi antenna with 10.7 dB of gain. Meanwhile, Olivier Kramer *et al* [6] have been studied micro-strip Yagi antenna in stacked structure. The gain of their antenna is 12 dB.

The work reported here is a combination between the OMYA and 1-D PCs structure acts as its cover in order to obtain high gain. The paper is structured as follows. First, an explanation of the proposed antenna geometry is discussed in Section 2 which consists of a description of the conventional design of OMYA and 1-D PCs cover. The simulation results are also discussed in section 3. Meanwhile, Section 4 is the conclusion of this work.

II. Antenna Configuration

A. Octagon Microstrip Yagi Antenna (OMYA)

Microstrip Patch Antenna (MPA) is one of the popular antennas due to it has several advantages. As can be seen in Figure 1, the MPA consists of a substrate, a conductor patch as radiator and another conductor as the ground plane. Meanwhile, the substrate is placed between the radiating patch and the ground plane.

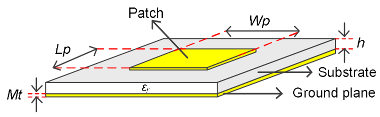

Figure 1. The Structure of MPA

On the other hand, MPA's low gain can be tackled by applying Yagi-Uda structure on the MPA. John Huang explains that the basic of microstrip Yagi-Uda antenna is consisted of 3 elements, namely Reflector element (R), Driven element and some Director element (D_n) [4].

The proposed OMYA here is designed on Rogers 5880 with thickness of 1.575 mm using [2]. The arrangement of the proposed OMYA is basically inspired by Gerald R. Dejean *et al* [5]. As depicted in Figure 2, there is a total of seven patch elements which consisted of 2 reflector elements (R_t & R_b), one driven element, 2 bottom director elements (D_{1b} & D_{2b}) and 2 top director elements (D_{1t} & D_{2t}). Each reflector element is placed behind the driven element. Meanwhile, the director elements are added in front of the driven element. The length and the width of reflector element are denoted by L_r and W_r.

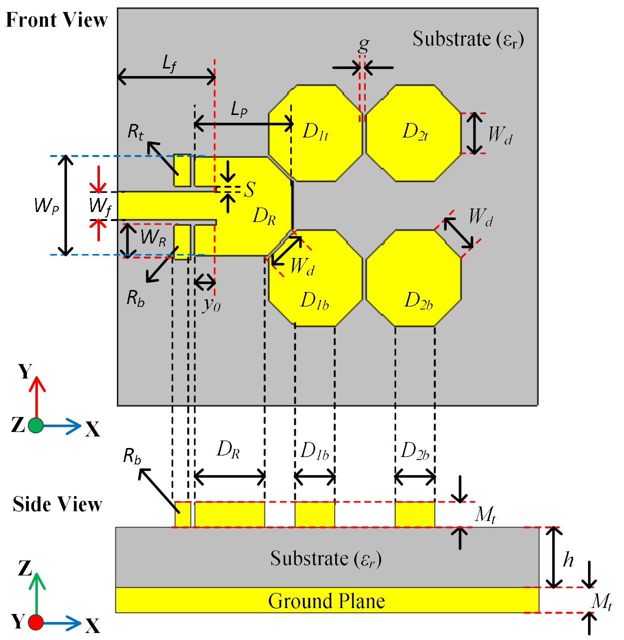

Figure 2. The Structure of OMYA

Octagon patch structure is chosen as the director elements in order to minimize the size of the proposed OMYA. Meanwhile, the rectangular patch is selected as the driven element. The aim of trimming two corners of the driven element is to reduce the surface-wave and to increase the mutual coupling between driven element and director elements.

The width and the length of the rectangular patch were calculated using (1, 2) [7]:

$$W = \frac{c}{2 \cdot f_o \cdot \sqrt{\frac{\varepsilon_r + 1}{2}}} \quad (1)$$

$$L = \frac{c}{2 \cdot f_o \sqrt{\varepsilon_{eff}}} - 2 \cdot \Delta L \quad (2)$$

Wherein velocity of light in frees space is given by c is 3 x 10^8 m/s. Meanwhile, ε_{eff} is the effective dielectric which can be determined using (3) [7]:

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left(\frac{1}{\sqrt{1 + 12 \cdot \frac{h}{w}}}\right) \quad (3)$$

and ΔL describe normalized extension of the length which can be obtained by (4) [7] :

$$\Delta L = 0.412 \cdot h \frac{(\varepsilon_{eff} + 0.3)\left(\frac{w}{h} + 0.264\right)}{(\varepsilon_{eff} - 0.258)\left(\frac{w}{h} + 0.8\right)} \quad (4)$$

For the feedline, there are a number of types of feeding methods and herein microstrip line feed method is selected. The reason is simple to match by controlling the inset position (y_o and S).

The width of transmission line (W_f) was designed using (5) [8]:

$$\frac{W}{d} = \frac{2}{\pi}\left[B - 1 - \ln(2B - 1) + \frac{\varepsilon_r - 1}{2\varepsilon_r}\left\{\ln(B - 1) + 0.39 - \frac{0.61}{\varepsilon_r}\right\}\right] \quad (5)$$

Where d is the substrate thickness and B can be determined by (6) [8]:

$$B = \frac{377\pi}{2Z_0\sqrt{\varepsilon_r}} \quad (6)$$

The basic structure of four director elements comes from microstrip Yagi antenna structure which has been reported by Gerald R. Dejean *et al* [5]. In order to minimize the size of the proposed antenna and to reduce surface-waves at the edge of the patch, four director elements have been modified into octagonal-shaped.

Based on the experimental results which have been done by M. Abu *et al* [9], octagonal shape has the highest percentage in bandwidth compared to others. Thus, this is the main reason behind selecting octagon-shaped as the director element geometry of the proposed OMYA.

J. Huang *et al* [4] explain that the gap (g) distance between two patch edges should be less than the dielectric substrate (ε_r) thickness. According to Gerald R. Dejean *et al* [5], the value of g must be less than $0.005\lambda_{eff}$ where the guide wavelength is denoted by λ_g can be calculated using (8) [8]:

$$\lambda_g = \frac{c}{f\sqrt{\varepsilon_r}} \quad (7)$$

B. One-Dimension Photonic Crystal (1-D PCs) Cover

In general, Photonic Crystal (PCs) is substrate material structure whose electric and magnetic varies periodically in One-Dimension (1-D), Two-Dimension (2-D) and Three-Dimension (3-D) [10]. It provides a good technique for enhancing performance of microstrip antenna.

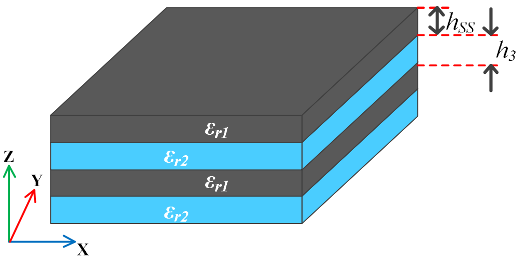

Figure 3. The structure of 1-D Photonic Crystal (*PCs*)

The simplest configuration among the three types of PCs is one-dimension (1-D) structure as shown in Figure 3. This configuration is also known as superstrate. 1-D PCs consist of one or more than one dielectric substrate where are placed above the conventional antenna. A study of gain enhancement using 1-D PCs or superstrate by David and Nicolaos [11] researched the influence of supestrate layer on the performance of single MPA and analysed it using a transmission line analogy.

They explain that the gain of MPA can be increased by placing superstrate layer which has permittivity (ε_r) >> 1 or permeability (μ) >> 1 [11]. The thickness of superstrate layer and air gaps (h_2 and h_3) give influence on gain enhancement as well. The theory of radiation by transmission analogies are well explained by David R. Jackson *et al* [11].

As shown in Figure 4, two high dielectric substrates which have ε_r of 10.2 with thickness of 2.5 mm are added above the proposed OMYA in order to obtain a higher gain. The geometry of the proposed high gain OMYA is depicted in Figure 4.

The proposed high gain OMYA has been simulated and optimized using full-wave EM simulator [12] to obtain the *S*-parameters in terms of return loss (S_{11}) and gain. In the interest of obtaining a best result in gain, a set of optimizations has been done by varying the thickness of 1st air gap (h_2) and 2nd air gap (h_3). The final optimized parameter values of the proposed high gain OMYA are tabulated in Table 1.

TABLE I
THE PROPOSED HIGH GAIN OCTAGON MICROSTRIP YAGI ANTENNA (OMYA) PARAMETERS

Parameter	Dimension (mm)
Air gap (h_2)	30
Air gap (h_3)	4
Superstrate Thickness (h_{ss})	2.5
Substrate Thickness (h)	1.575
Total height of the proposed antenna (H_t)	39
Total width of the proposed antenna (W_t)	70
Total length of the proposed antenna (L_t)	75
Thickness of copper (M_t)	0.035
Spacing between element (g)	0.7
Length of patch (L_p)	17.4
Width of patch (W_p)	18
Width of 50 Ω transmission line (W_f)	4.9
Length of 50 Ω transmission line (L_f)	15
Length of reflector element (L_r)	6.5
Width of reflector element (W_r)	9
Length of the inset (Y_0)	3.5
Spacing of the inset (S)	0.9

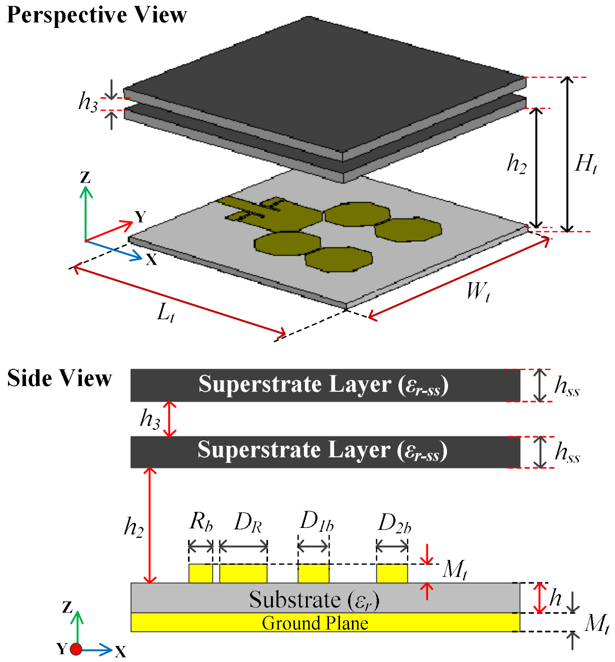

Figure 4. Perspective and side view of the proposed high gain OMYA

III. Simulated Results

This section describes the simulated results of the proposed high gain OMYA. The simulation frequency range is start from 3 GHz to 8 GHz. Figure 5 and Figure 6 show the simulated S_{11} and radiation pattern which are obtained by using the calculated and optimized design parameters in Table I.

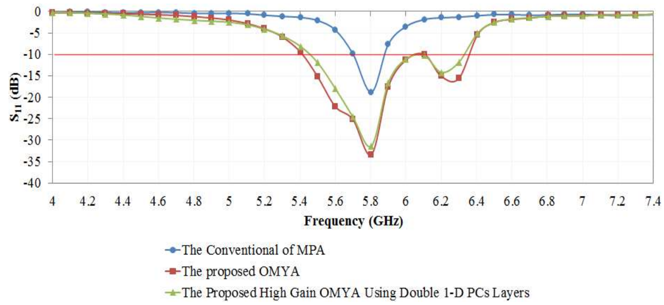

Figure 5. The simulated S_{11} of the proposed high gain OMYA compared to the conventional of MPA

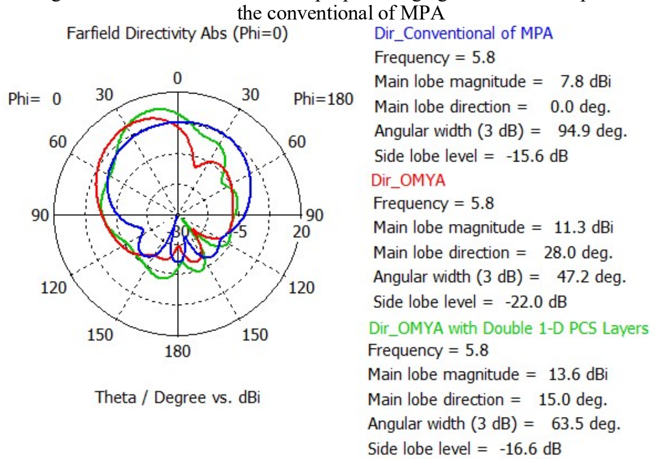

Figure 6. The simulated 2-D radiation pattern of the proposed high gain OMYA compared to the conventional of MPA

All simulated results are tabulated in Table II. According to Table II, the gain of the proposed OMYA is 11.16 dB with bandwidth of 15.97%. It indicates that an improvement of 3.18 dB can be achieved by applying octagon Yagi structure. The angle of maximum radiation for the OMYA is 28° from the broadside direction (*z-axis*). It expresses that the microstrip Yagi antenna cannot totally radiates power at end-fire direction (*x-axis*). It caused by a microstrip patch antenna requires a ground plane.

Thereafter, two superstrate layers are placed above the proposed OMYA to improve the gain. The simulated result shows that the main lobe direction at 15° which is closer to broadside than that of the OMYA without using double superstrate layers. Meanwhile, the gain of the proposed high gain OMYA is 13.45 dB and the bandwidth is 14.89 %. Hence, the gain of the high gain OMYA is 2.29 dB higher than the proposed OMYA without using 1-D PCs cover. It gives an evidence that 1-D PCs cover can be utilized to increase the gain as well.

TABLE II
SIMULATION RESULTS OF SIMULATED S11, VSWR AND GAIN

Type	Parameters			
	Freq.	***BW (%)***	***S11 (dB)***	***Gain (dB)***
The conventional MPA	5.8 GHz	2.75	-23.87	7.98
The proposed OMYA		15.97	-34.39	11.16
The proposed high gain OMYA using double 1-D PCs layers		14.89	-32.57	13.45

Table III summarizes the results from simulation of the proposed high gain OMYA and recently reported microstrip Yagi antennas. It can be observed here that the proposed high gain OMYA has higher gain and wider bandwidth other microstrip Yagi antennas [4-6].

TABLE III
COMPARISON RESULTS

Type	Parameters				
	Freq (GHz)	***BW (%)***	***BW (MHz)***	***Gain (dB)***	***Overall Size (mm^3)***
The proposed high gain OMYA using 1-D PCs cover	5.8	14.89	863	13.45	70x75x39
Single Microstrip Yagi [5]	5.2	10	~405	10.7	112x112
Dipole Stacked-Yagi [6]	5.8	14	~812	12	80x80x29

IV. Conclusion

A high gain OMYA using 1-D PCs cover has been designed, simulated and optimized in this paper. The simulated results indicate that the proposed high gain OMYA has gain of 13.45 dB and bandwidth of 14.89% with a size of 70 x 75 x 40 mm^3. Due to it has high gain and wider bandwidth, it is suitable for WiMAX application. In conclusion, an improvement of 5.47 dB in gain has been achieved by applying octagon-shaped Yagi structure and 1-D PCs method. Hence, those methods can be utilized to improve the performance of the conventional MPA in terms of gain and bandwidth.

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