The Design of Triple Band Antenna Applied in WLAN and Wimax System

Xiaofeng Wan
Department of Electronic Engineering
Tianjin University of Technology and Education
Tianjin, China

Hongxing Zheng
Department of Electronic Engineering
Tianjin University of Technology and Education
Tianjin, China

***Abstract*—In this paper, two different triple band antennas are proposed and demonstrated. Both of them used microstrip feed, the one adopt multi-branch manner, the other through opening slot in radiation patch with comb- and ring-shape and undoes circular gap in ground plane to realize tri-band characteristic. The design of the two kinds of antenna is based on the electromagnetic simulation software HFSS15.0.2 and measured by the vector network analyzer AV3629. The measurement display that branches antenna's -10dB bandwidth are respectively 2.24-2.55GHz, 3.3-3.68GHz and 4.9-5.9GHz, and slot antenna's -10dB bandwidth are respectively 2.38-2.48GHz, 3.5-3.62GHz and 5.66-5.81GHz, experimental results showed that the both the two kinds of tri-band antenna can be applied to WLAN and WiMAX system.**

Keywords—Tri-band; branch antenna; slot antenna; WLAN; WiMAX

I. INTRODUCTION

In recent years, the development of modern wireless communication system is booming fast, mobile terminal needs to work on a plurality of communication frequency bands in order to cooperate to complete the transmitting and receiving task in the process of communication. But the mobile terminal space is very limited, when several different single frequency antennas used at the same time may cause serious coupling, then reducing communication quality. Therefore the multi-frequency antenna has been widely applied to a variety of wireless communications area. Wireless local area network (WLAN) and worldwide interoperability for microwave access (WiMAX) are gradually replacing the cable network model of old style [1] ~ [3], and no longer restricted by area and position. The working frequency bands of the WLAN are 2.45GHz (2.4-2.484GHz), 5.25GHz (5.15-5.35GHz) and 5.8GHz (5.725-5.825GHz), the working frequency bands of the WiMAX are 2.5GHz (2.5-2.69GHz), 3.5GHz (3.4-3.69GHz) and 5.5GHz (5.25-5.85GHz) [4] ~ [6]. The WLAN is provided with strong flexibility and mobility, but with narrow coverage. For WiMAX, its coverage is relatively broad. If we can use WLAN and WiMAX at the same time, the communication quality can be further optimized.

The compact dual band broadband printed antenna which used for WLAN are mentioned in paper[7], although it is provided with advantages of simple structure, wide high frequency bandwidth, but its S_{11} is not stable in high frequency, and the antenna is not small enough. The circularly polarized printed triple band antenna in the paper [8] is possessed with simple structure and unique design, using the method of slotting in the ground to achieve the tri-band antenna characteristics, but its large size and bad effect in the low frequency is not very good. Two type of triple band antenna are designed in this paper. One of them used multi-branch method to achieve multi-band antenna in the work function, another one through opening slot in the radiation patch and the ground plane to reach the final target. Both of them have the advantages of simple structure and small size, and can be perfectly worked in the WLAN and WiMAX system.

II. DESIGN

A. Branches structure antenna

1) The structure design of branches antenna

When designing microstrip antenna, choose suitable dielectric substrate is very important. Assume the dielectric constant is ε_r, if the working frequency of the rectangular microstrip antenna is f, then the width of radiation patch can be calculated with the formula following [9] ~ [11]

$$w = \frac{c}{2f}\left(\frac{\varepsilon_r + 1}{2}\right)^{-\frac{1}{2}}$$

In the formula, c is the light speed. The half length of radiation patch is $\lambda_e/2$; λ_e is the wavelength in the medium here,

$$\lambda_e = \frac{c}{f\sqrt{\varepsilon_e}}$$

Considering the shortening effect of the edge, the actual radiation unit length L should be

$$L = \frac{c}{f\sqrt{\varepsilon_e}} - 2\Delta L$$

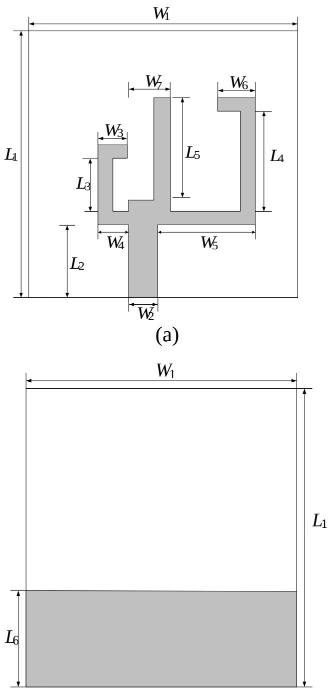
In the formula, ε_e is the effective dielectric constant, ΔL is the gap length of equivalent radiation, and the calculation formula is as follows [12] ~ [15]:

$$\varepsilon_e = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left(1 + 12\frac{h}{w}\right)^{-\frac{1}{2}}$$

$$\Delta L = 0.412h\frac{(\varepsilon_e + 0.3)(w/h + 0.264)}{(\varepsilon_e - 0.258)(w/h + 0.8)}$$

According to the above method of antenna design, a multi branches printed antenna with a simple structure is proposed, the radiation patch used three L shaped structure, the center frequency of the designed antenna are corresponding 2.4GHz, 3.5GHz and 5.4GHz. If electromagnetic propagated in the free space, the corresponding $\lambda/4$ of the three frequency points are 31.25mm, 21.5mm and 14mm, but if spread in the Rogers 3.38 RO4003 medium, the corresponding $\lambda/4$ are 17mm, 11.75mm and 7.65mm. However the propagation of electromagnetic is going through both free space and medium, so the $\lambda/4$ are between the two respectively, namely the $\lambda/4$ range of working frequency of 2.4GHz, 3.5GH and 5.4GHz are 17-31.25mm, 11.75-21.5 and 7.65-14mm respectively. Owing to the influence of the coupled three radiation structures and the microstrip feed line, the corresponding wavelength of $\lambda/4$ monopole antenna will be slightly changed.

The antenna is printed on the dielectric substrate which size is $L_1 \times W_1 \times H$ and relative dielectric constant is Rogers RO4003 3.38. The structure of the branches antenna was shown in Figure 1. The antenna is composed of a dielectric substrate, L shaped radiation patch, T shaped microstrip feed line and the ground plane. The width of L shaped radiation patch is w, and the horizontal length of T shaped microstrip feed line is $W_6+W_2+W_7$.



(a)

(b)

Fig. 1. the structure of branches antenna: (a) the front of structure, (b)the back of structure.

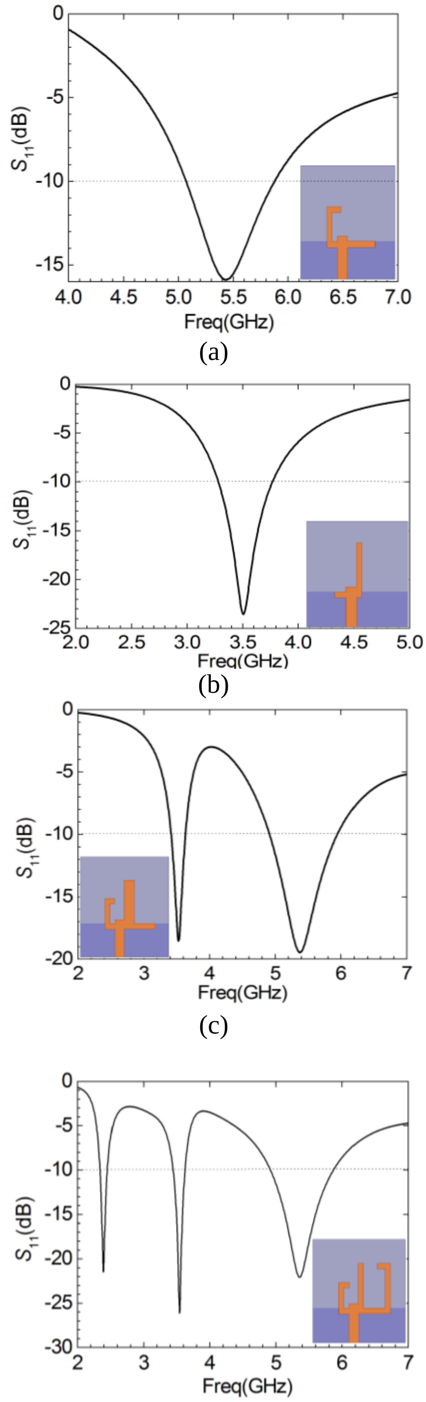
2) The analysis of branches of the antenna structure

(a) When there is only inverted L shape structure in the left side of the antenna, the S11 curve of the antenna is shown in Figure 2(a), at this time the center frequency of antenna is around 5.4GHz, and the frequency range is 5.1-5.9GHz.

(b) When there is only L shape structure in the middle of the antenna, the S_{11} curve of the antenna is shown in Figure 2(b), at this time the center frequency of antenna is around 3.5GHz, and the frequency range is 3.3-3.75 GHz.

(c) If we combine the left side inverted L shape and the middle L shape together, two center frequency of the antenna appeared, around 2.4GHz and 5.4GHz respectively, the frequency range are 2.24-2.65GHz and 4.86-5.96GHz, the results of S_{11} is shown in Figure 2(c).

(d) On the bases of the above, we add an inverted L shape in the right side of the antenna, the result of S_{11} is shown in Figure 2(d). Their -10dB band range are 2.24-2.55GHz, 3.3-3.68GHz and 4.9-5.9GHz respectively.



(a)

(b)

(c)

(d)

Fig. 2. the S_{11} of branches antenna (a) only left side inverted L shape existed (b) only middle L shape existed (c) both left side inverted L shape and middle L shape existed (d) left and right side inverted L shape and middle L shape all existed.

Through the analysis of the above several cases, the left side inverted L shape radiation unit generates a center frequency point near 5.4GHz, the middle L shape radiation unit generates a center frequency point near 3.5GHz, and the right side inverted L shape radiation unit generates a center frequency point near 2.4GHz, therefore combine the three radiation element together, and adjust the size of each part, the purpose of the three bands are realized.

B. Slot antenna

1) The radiation mechanism of annular slot antenna

In general, annular slot in infinite conducting plate is equivalent to an annular distribution of surface magnetic current, expressed as [16] ~ [17]

$$\boldsymbol{M}(\rho,\varphi)=\boldsymbol{E}_a(\rho,\varphi)\times \boldsymbol{n}$$

In the formula, $\boldsymbol{M}$ is the equivalent magnetic current, $\boldsymbol{E}_a$ is the electric field on the slot, ρ and φ are polar parameters, and n is the unit vector perpendicular to the conductor plate. Because the annular slot antenna and electric circular antenna meets the duality principle, the distribution of electromagnetic wave on the far zone plane of the ring slot antenna can be easily got

$$\boldsymbol{E}_\theta = e^{-jkr}\frac{rkE_a}{2a}J_1(rk\sin\theta)$$

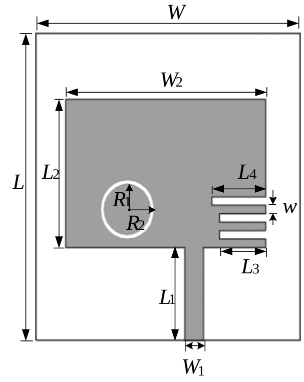
$$\boldsymbol{H}_\varphi = e^{-jkr}\frac{rk\eta_0 E_a}{2a}J_1(rk\sin\theta)$$

In the formula, ($\boldsymbol{E}_\theta$, $\boldsymbol{H}_\varphi$) expressed as far field distribution, r is radiation distance of electromagnetic wave, k is the propagation constant, η_0 is vacuum wave impedance, J_1 is the first order Bessel functions, r_1 and r_2 represent the outer and inner radius circle respectively, the center frequency of the ring slot antenna can be expressed

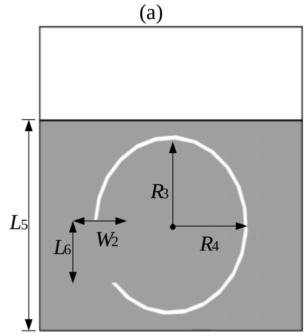
$$f=\frac{c}{2\pi(r_1+r_2)}$$

2) The structure of antenna

The structure of the antenna showed in Figure 3, the antenna is printed on the dielectric substrate which size is $L\times W\times H$ and relative dielectric constant is 4.4. This antenna is composed of FR4 dielectric substrate, microstrip feed line, radiation patch and ground plane. The dimensions of microstrip feed line and the radiation patch in Figure 3 are $L_1\times W_1$ and $L_2\times W_2$. There are rectangular slot comb structure and closed ring groove in the interior, and rectangular slot in the lower right corner of the rectangular radiation patch, the dimensions of the bottom two rectangular groove and the top of the rectangular groove are $L_3\times W$ and $L_4\times W$, the space between the rectangular groove is w, they adjacent placed to form a comb structure. The closed ring slot located in the bottom left of the rectangular radiation patch, the radius of the round are respectively R_1 and R_2. There is unclosed annular slot opened in the ground plane which size is $L_5\times W$, the radius of the round are respectively R_3 and R_4, located in the center of the ground which left filled by a rectangle which size is $L_6\times W_2$.



(a)

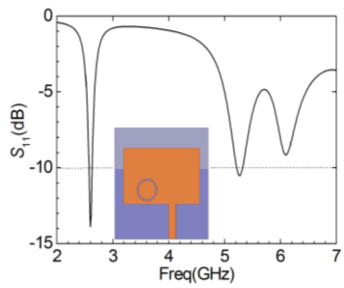


(b)

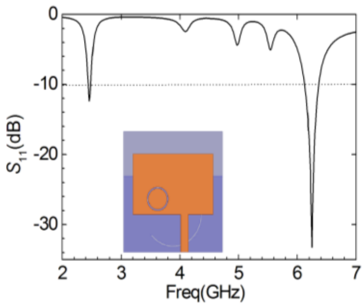
Fig. 3. the structure of slot antenna: (a) the front of structure, (b) the back of structure.

3) Experiment analyses

The triple frequency comb slot antenna is simulated by HFSS15.0.2. From simulation results and analysis, a conclusion got that when only opening the annular groove in the radiation patch, the resonant frequency of the antenna is 2.6GHz, as shown in Figure 4(a), its -10dB bandwidth in the range of 2.57-2.63 GHz, belongs to WiMAX frequency range, but it does not work well in the resonant frequency of 5.2GHz and 6.1GHz. Figure 4(b) shows the antenna's S_{11} while opening the annular groove in the radiation patch and opening gap slot in the ground, it gets -35dB return loss S_{11} at 6.2GHz, its -10dB bandwidth range from 6.13 to 6.36GHz. In order to improve the ability of radiation and realize the characteristics of triple frequency, the comb shaped groove is arranged on the radiation patch below the right, then three frequency appeared, and then scan the width of the ring slit, that seems to scan the R_2, the result is showed in Figure 5, when R_2=3.5mm, best effect is got. The final result as shown in Figure 6, the antenna got lowest S_{11} in 2.4GHz, 3.5GHz and 5.8GHz, their -10dB bandwidth are 2.38-2.48GHz, 3.5-3.62GHz and 5.66-5.81GHz respectively. With this slot mode, we can realize the collaboration use of WLAN and WiMAX.



(a)



(b)

Fig. 4. the S_{11} of slot antenna (a) only opening the annular groove in the radiation patch (b) opening the annular groove in the radiation patch and opening gap slot in the ground.

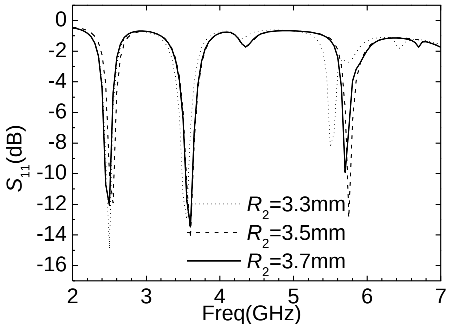
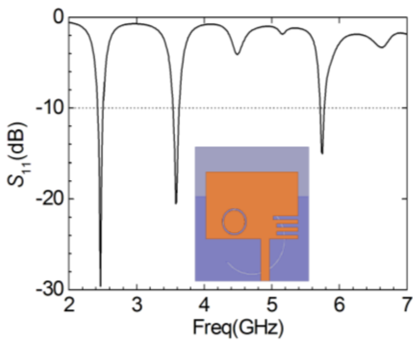


Fig. 5. the scan result of S_{11} of R_2.



(c)

Fig. 6. the final S_{11} of slot antenna.

III. THE RESULTS OF THE DESIGN

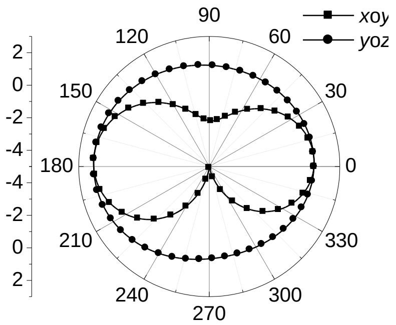
Based on the detailed analysis in the front, the antenna parameters obtained are shown in table 1 and table 2. The far field radiation characteristics of the antenna are simulated. Selected the working frequency of 2.4GHz, 3.5GHz and 5.4GHz as the reference frequency of the branches antenna, and selected the 2.4GHz, 3.5GHz and 5.8GHz as the reference frequency of the slot antenna. The far field radiation characteristics through the xoz plane and yoz plane antenna can be observed in Figure 7 and Figure 8.

TABLE I. THE PARAMETERS OF BRANCHES ANTENNA AFTER OPTIMIZATION (MM)

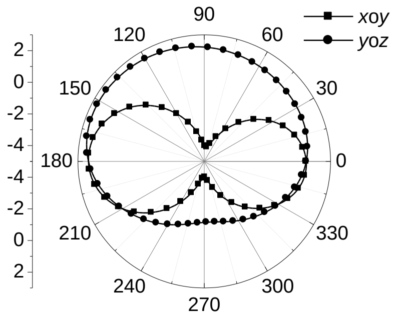
L_1	L_2	L_3	L_4	L_5	L_6	H	w
35	9.7	8.9	15.2	15.2	11.5	1.52	1.8
W_1	W_2	W_3	W_4	W_5	W_6	W_7	
34	3.5	3.7	5.3	4.6	3.7	11.8	

TABLE II. THE PARAMETERS OF SLOT ANTENNA AFTER OPTIMIZATION (MM)

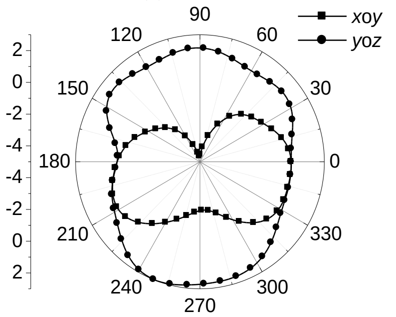
L	L_1	L_2	L_3	L_4	L_5	w	H
35	11	17.5	6	7	22	1	1.5
W	W_1	W_2	R_1	R_2	R_3	R_4	
32	2.4	26	3.5	3	9.5	9	



(a) 2.4GHz

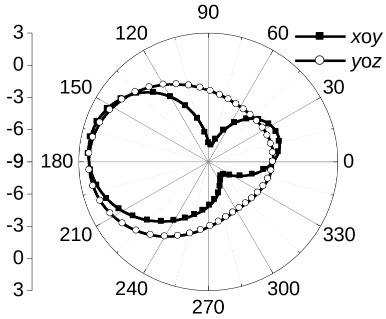


(b) 3.5GHz

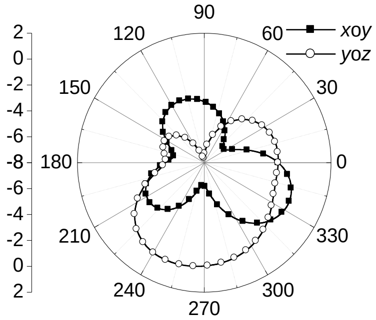


(c) 5.4GHz

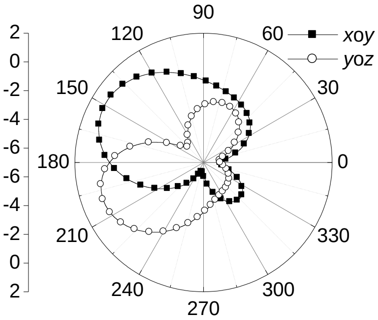
Fig. 7. Far field radiation pattern of branches antenna.



(a) 2.4GHz



(b) 3.5GHz



(c) 5.8GHz

Fig. 8. Far field radiation pattern of slot antenna.

According to the after optimization size, corresponding physical antenna are made in Figure 9 and Figure 10. Using the high performance RF integration vector network analyzer AV3629 to measure, the measured S_{11} and VSWR are shown in Figure 11 and Figure 12, as a contrast, the simulation curves of the same geometrical parameters of the antenna is placed in. Owing to the manufacture conditions, the antenna loss and some human factors, a small scope fluctuation measurement is existed. Although the difference in the high frequency part of the antenna is relatively large, but the overall trend of the experimental results and the simulation results are the same.

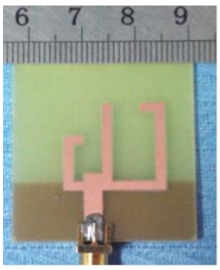
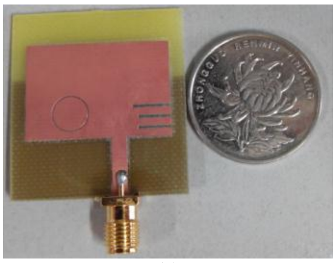
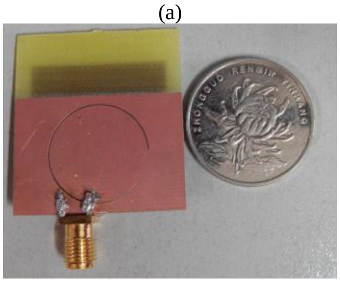


Fig. 9. the entity of branches antenna.

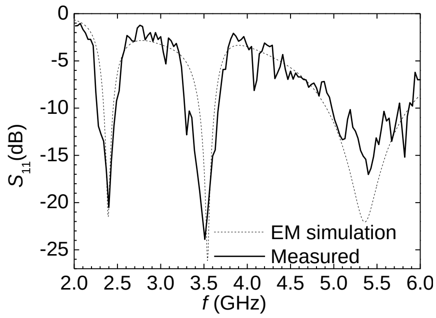


(a)

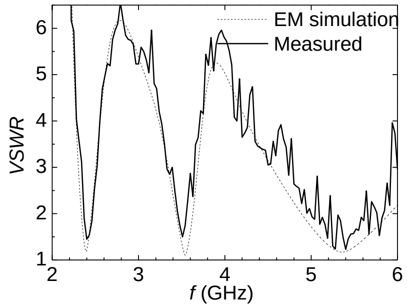


(b)

Fig. 10. physical figure of slot antenna: (a) the front, (b) the back.

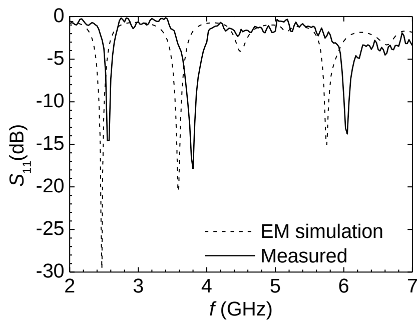


(a)

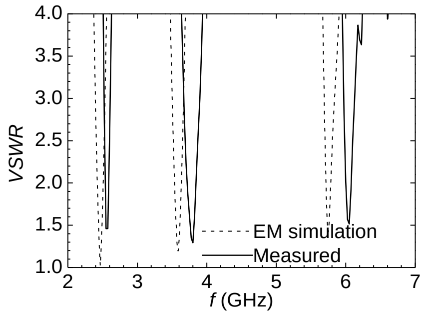


(b)

Fig. 11. the contrast between EM simulation and real measurement of branches antenna: (a) S_{11}, (b) *VSWR*.



(a)



(b)

Fig. 12. the contrast between EM simulation and real measurement of slot antenna: (a) S_{11}, (b) *VSWR*.

IV. CONCLUSION

This paper presents two tri-band printed antennas, the first one adopt the radiation of a combination of three L-shaped metal patch, the second used radiation slotted and open gaps on the ground approach, allowing the antenna to achieve three-frequency characteristics, eventual can work in WLAN and WiMAX systems. In addition, simple structures, small size, easy to integrate with microwave circuits make them great value in use. However the opening slot in ground affected the second antenna's omnidirectional radiation characteristic, which should be further studied.

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