Design of a Three Dimensional Folded Monopole Antenna Using Current Flow

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Abstract

A new type of monopole antenna whit broadband characteristics is presented in this article. To reduce the size of the antenna, its upper part is folded. By separating the current flow, the resonance in the shorter part is in the higher band; and the longer part resonates in the lower band. This gives the broadband characteristics of the antenna. Slots on the corner using an oblique line improve the impedance matching and bandwidth. The measurement results show that the bandwidth operates from 0.848~0.992 GHz and 1.744~2.528 GHz, and the radiation patterns are in an omni-directional shape.

Key words : Three Dimensional Folded Atenna, Monopole Antenna, Current Distribution.

Ⅰ. Introduction

With the continuing development of modern wireless communication systems, and with the rapid increase in the number of the users, wireless antennas have become an important part of wireless communication systems. Along with this increase comes a need for better performance. An antenna should provide multi-band or broadband capabilities. In addition, it should be small and light. Currently, there are three main antennas for mobile phones: monopole, planar inverted-F, and ceramic chip types. The monopole antenna is one of the most popular types used in mobile communications, owing to its simple structure, omni-directional radiation characteristics, low profile and light weight and the fact that it is an internal type of antenna[1],[2].

The characteristics for a planar monopole antenna can be approximately calculated like an equivalent cylindrical monopole antenna having the same height. The width of the monopole antenna is equivalent to the circumference of the cross-section of the cylindrical monopole antenna. The equivalent radius is:

$$r = W/2\pi \qquad (1)$$

where W is the width of monopole antenna.

The length of a l/4 monopole antenna is half that of a l/2 dipole antenna. From the above equation, the resonant frequency is given by[3]

$$f_L = 7.2/(L + r + p) \quad [\mathrm{GHz}] \qquad (2)$$

where f_L is the resonant frequency, L is the length of the antenna patch, and p is the length between the ground plane and the patch.

It has been shown by research that a monopole antenna can have broadband characteristics when the shape of antenna is changed, such as being folded. The impedance and bandwidth of the antenna will increase, but the radiation characteristics will not change.

Ⅱ. The Antenna Design

The antenna occupies an area of 38×21 mm^2, with its overall size being 38×88×1 mm^3. The substrate is made of FR-4 with a permittivity value of 4.62. The gap between the ground plane and the long patch is about 9 mm. For support, a piece of styrofoam with a permittivity value of 1.03 is between the antenna and the substrate. The permittivity of styrofoam approximates air. By the simulation results between the air and the styrofoam, the results of the antenna used with the styrofoam were similar to the antenna without styrofoam. The patch of the antenna is 3.5 mm higher than the substrate. The antenna is fed by a 50 Ω microstrip line, and an additional trapezoidal part is included to connect the antenna patch to a feed line that achieves a broad bandwidth[4]. In addition, the antenna is folded at the top of the patch along the dashed lines shown in Fig. 1. This reduces the size of the antenna by approximately 25 %[5].

The antenna patch is divided into an inner patch and an outer patch with slots, as shown in Fig. 1. The slots on the corner use an oblique line with an angle θ in the vertical direction(in the dashed ellipse shown in Fig. 1). This improves the impedance matching and bandwidth. When the size of the outer patch is increased, the resonant frequency moves to a lower frequency. Through a

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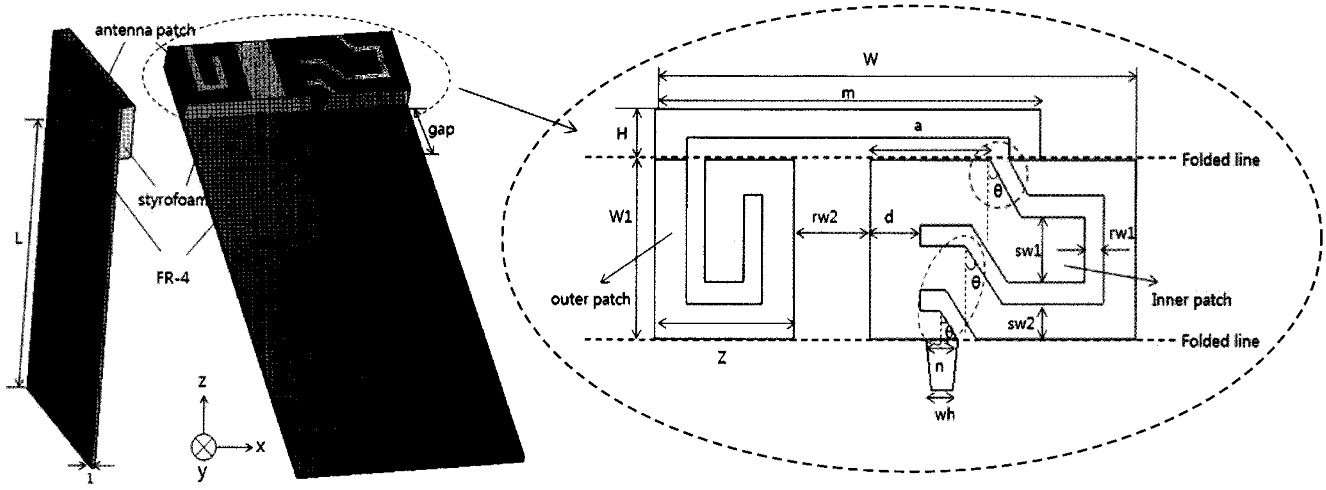


Fig. 1. Configurations of the proposed antenna.

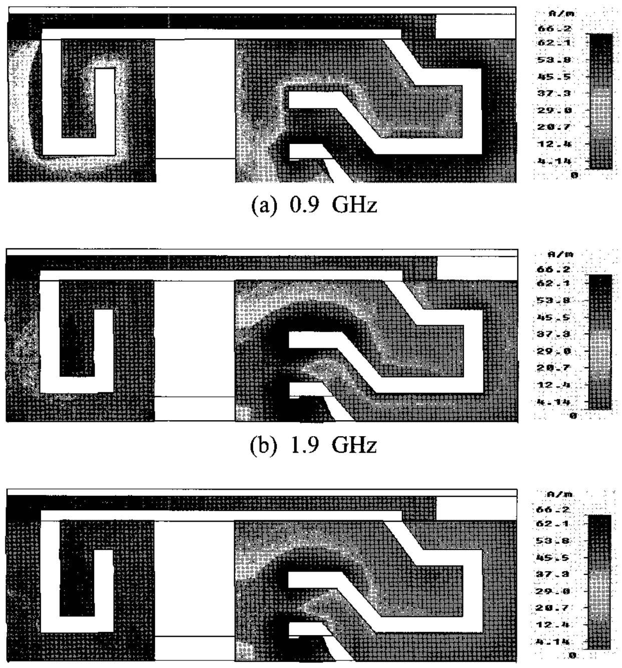
Table 1. Optimized parameters of the proposed antenna.

Parameter	Value(mm)	Parameter	Value(mm)
a	11	*sw*2	2.5
d	4	*rw*1	1.5
gap	9	*rw*2	6
H	3.5	*W*	38
L	66.5	*W*1	12.5
m	32	*Z*	11
n	2.5	θ	45
*sw*1	4.5	*wh*	1.7

simulation and optimization with CST MWS software, the parameters of the antenna were determined(Table 1).

Ⅲ. The Simulation and Optimization

Fig. 2 shows the current distributions on the proposed antenna surface at 0.9 GHz, 1.9 GHz and 2.2 GHz. These distributions show that the current flow changes according to the resonant frequency. The current distribution at 0.9 GHz is mainly distributed in the outer patch. This implies that the outer patch is the major radiation element for the lower resonant frequency. For the distributions at 1.9 GHz and 2.2 GHz, the current is mainly distributed on the inner patch and right part of the outer patch. This indicates that the right patch is the major radiation element for the higher resonant frequencies. The current distributions at 1.9 GHz were thicker and longer than at 2.2 GHz, due to the one-quarter wavelength of the operating frequency at 1.9 GHz being longer than one-quarter wavelength of the operating frequency at 2.2 GHz.



(a) 0.9 GHz

(b) 1.9 GHz

(c) 2.2 GHz

Fig. 2. Current distributions on the antenna surface.

For a suitable observation of the influence of the different parameters on the impedance bandwidth and to obtain the expected band, the parameters were optimized. Only one parameter was investigated at a time, while the other parameters were kept invariant. The parameters that had an effect on the operating bandwidth were mainly found in the length of the proposed antenna *W*, the width of slot *rw*1, the width between the left patch and the right patch *rw*2, the angle between the slots on the corner, the vertical direction when it is θ, and the gap.

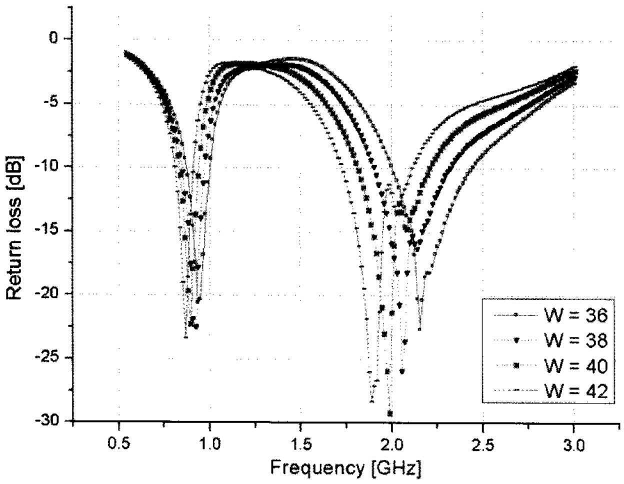


Fig. 3. Simulation results of the return loss for parameter *W*.

In Fig. 3, the length of the antenna *W* was changed while the other parameters remained fixed. It was observed that when the length increased, the lower and higher resonant frequency bands moved lower. When the size was close to 38 mm, the desired band was attained.

*rw*1 is the width between the inner patch and outer patch, so the coupling effect can be generated when the length of the antenna has been determined. As shown in Fig. 4, the lower resonant frequency bands moved to the lower band and became narrower when the *rw*1 parameter increases. That means when *rw*1 becomes bigger, the length of the inner patch becomes shorter. Actually, the inner patch controls the higher frequencies. This is caused by the parameter *rw*1 affecting the bandwidth at higher frequencies. When the size of the *rw*1 was close to 1.5 mm, the desired band was attained.

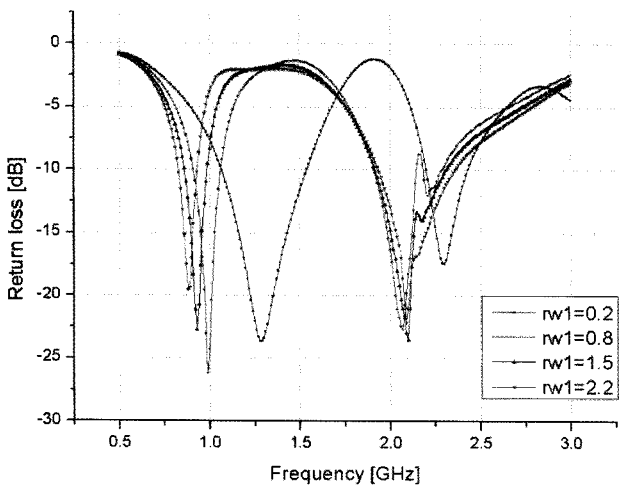


Fig. 4. Simulation results of the return loss for parameter *rw*1.

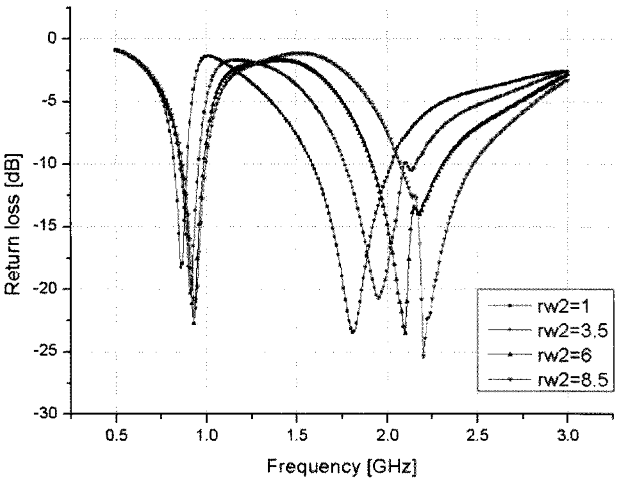


Fig. 5. Simulation results of the return loss for parameter *rw*2.

Fig. 5 shows the simulation results for parameter *rw*2. As the *rw*2 increases, the lower resonant frequency bands move slowly to the higher bands and become wider. On the other hand, the higher resonant frequency bands move quickly to the higher bands. Therefore, the *rw*2 parameter controls the higher resonant frequency bands.

From Fig. 6, the variation is indicated by the angle θ between the slots in the corner in the dashed ellipse (Fig. 1). These are in a vertical direction. It is observed that the lower resonant frequency bands move to the lower band as the angle θ increases. The higher resonant frequency bands also move to the lower band and the return loss improves. Parameter θ clearly influences the impedance matching in the higher band owing to the ample current distribution at the slot corners. When θ is 45 degrees, it satisfies the expected band.

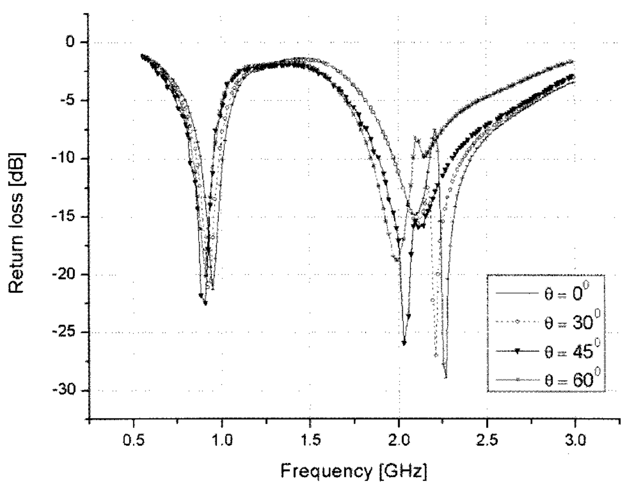


Fig. 6. Simulation results of the return loss for parameter θ.

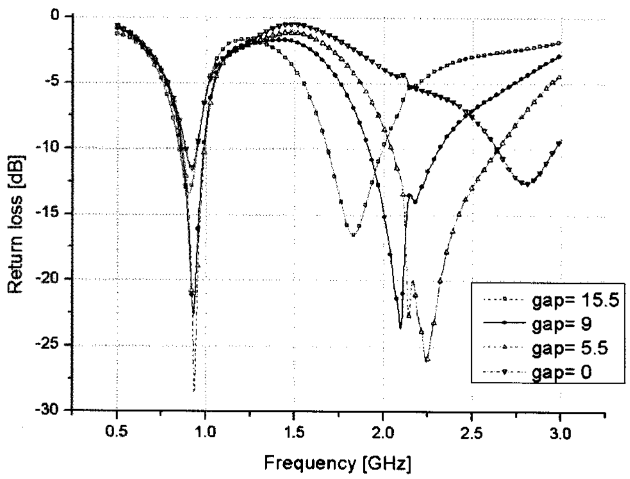


Fig. 7. Simulation results of the return loss for the parameter gap.

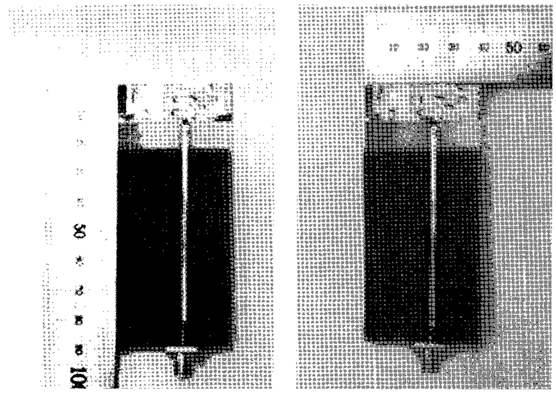
The size of the gap between the ground plane and the patch also affects the higher resonant frequency. The gap size was increased while the size of the antenna patch and the overall parameters were fixed; on the other hand, the size of ground plane was reduced from the top. The expected higher resonant frequency bands moved to the lower band, while the lower resonant frequency bands mostly remain stable. The optimized size of the gap is 9 mm.

During the parameter optimization process, it was observed that the parameters influenced the return loss as they become distributed mainly in the right part of the antenna patch. The current distribution on the right part is thicker than that of the left part. The higher resonant frequency bands can be adjusted by tuning the length of the ground plane.

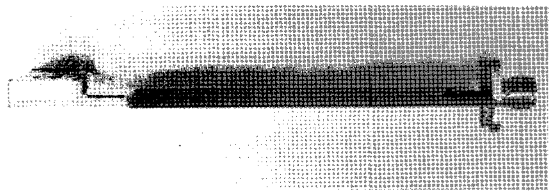
Ⅳ. The Results and Discussions

The fabricated proposed antenna is shown in Fig. 8. As part of this study, the performance characteristics of the antenna were measured.

The return loss of the antenna was measured using a network analyzer. In order to verify the performance of the proposed antenna, the simulated and measured results of the return loss were compared(Fig. 9). The return loss patterns are very similar. The bandwidth of the simulation results are 0.154 GHz(0.827~0.981 GHz) and 0.633 GHz(1.848~2.481 GHz). The bandwidth of the measurement results are 0.144 GHz(0.848~0.992 MHz) and 0.784 GHz(1.744~2.528 GHz). The obtained bandwidths cover to the GSM900(0.880~0.960 GHz), PCS(1.750~1.870 GHz), WCDMA(1.920~2.170 GHz), WiBro(2.30~2.39 GHz) and WLAN(2.40~2.48 GHz) bands with a VSWR<2.5:1.



(a) Front view of the antenna



(b) Lateral view of the antenna

Fig. 8. Fabricated proposed antenna.

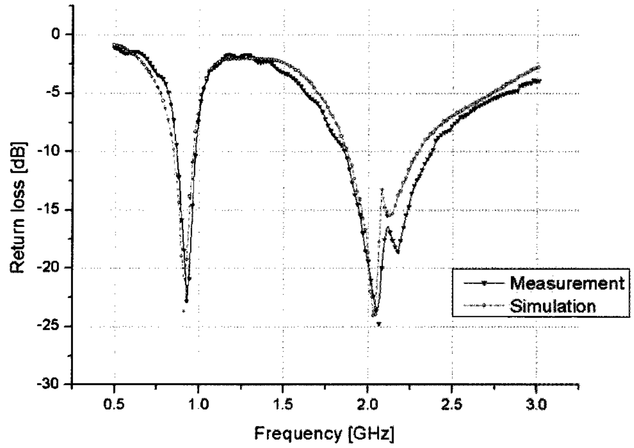
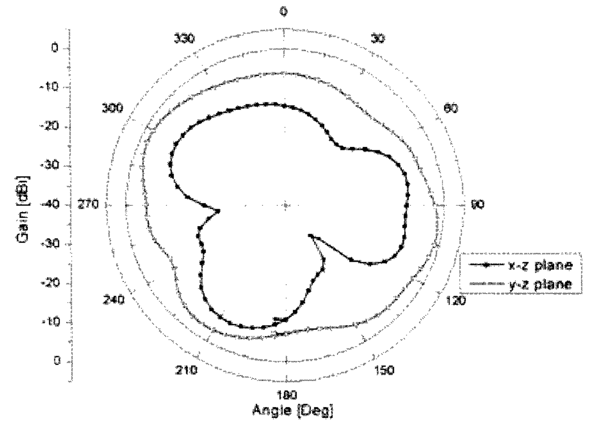


Fig. 9. Simulated and measured results of the return loss.

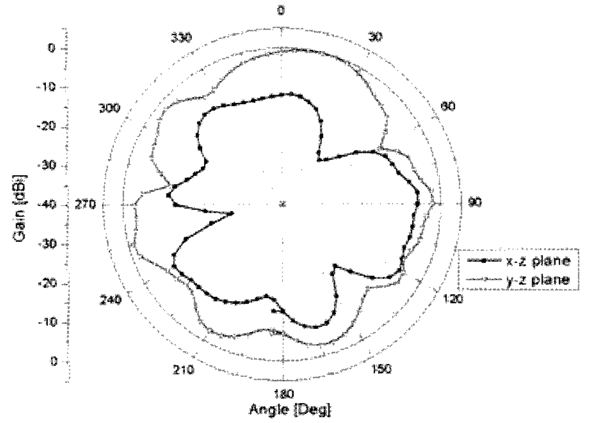
The measured radiation patterns were at the resonant frequencies of 0.9, 1.8, 2 and 2.3 GHz(Fig. 10). The radiation patterns have omni-directional shapes, which are typical for a monopole-type antenna. The measured average gains are −2.83, −2.26, −2.64, and −2.45 dBi at 0.9 GHz, 1.8 GHz, 2 GHz and 2.3 GHz, respectively.

Ⅴ. Conclusion

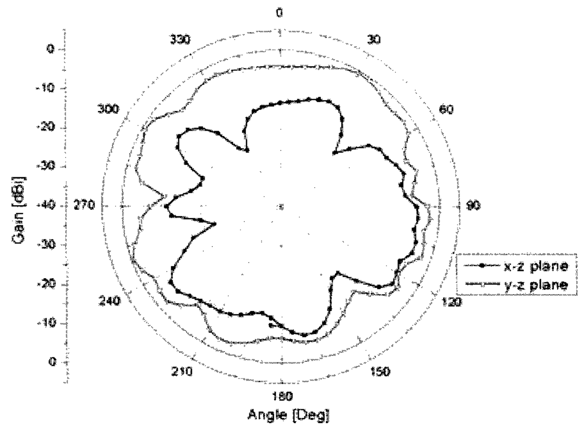
A compact broadband antenna is proposed in this paper. The size of the proposed antenna was reduced by folding it at the top of the patch. The characteristics of the proposed antenna were investigated and validated experimentally. The proposed antenna achieved suitable



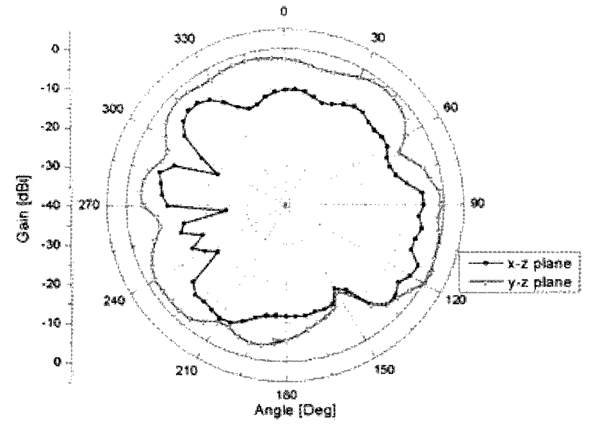
(a) 0.9 GHz



(b) 1.8 GHz



(c) 2 GHz



(d) 2.3 GHz

Fig. 10. Measured radiation patterns.

impedance matching, produced stable radiation patterns and showed bandwidths of the return loss at less than -7.35 dB at 0.154 GHz(0.827~0.981 GHz) and 0.633 GHz (1.848~2.481 GHz). The radiation patterns have omni-directional shapes. In conclusion, this antenna would be applicable to GSM900, PCS, WCDMA, WiBro and WLAN services.

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