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A NOVEL WIDEBAND MULTILAYERED MICROSTRIP ANTENNA WITH SHORTING PINS AND ARC-SHAPED APERTURES LOADED

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Abstract—A novel wideband multilayered microstrip antennas with shorting pins and arc-shaped apertures loaded is designed and fabricated. The antenna consists of two dielectric substrates and a quasi H-shaped circular patch with five shorting pins and four arc-shaped apertures loaded on the upper layer. Multiple layers are employed to achieve wide bandwidth by stacked electromagnetic coupling. The arc-shaped apertures and shorting pins are used to excite multiple modes, which can change the cavity's electromagnetic characteristic by influencing the series-parallel connection inductance, so that the wide bandwidth is obtained. Effects of the key parameters on the wideband performance are also studied, and a set of optimum values is chosen for the antenna design. The impedance bandwidth ($VSWR < 2.0$) of the proposed antenna reaches 2.59 GHz with the measured results, which means the relative impedance bandwidth is expanded up to 34.7% across 6.17 to 8.76 GHz. Simulation results agree well with measured ones.

1. INTRODUCTION

Microstrip antennas have been studied extensively owing to attractive advantages such as low profile, ease of integration with active devices, and conformability to mounting hosts [1]. The above-mentioned advantages make them suitable for numerous applications [2, 3]. The next generation of microwave wireless systems requires low-profile miniature antennas that not only are lightweight but also, in particular, possess wide bandwidth. The need of electromagnetic compatibility

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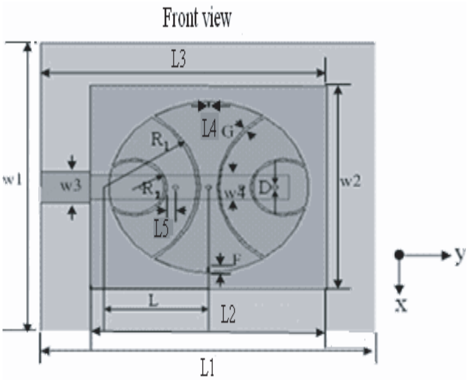
and transmission of data also requires wider operation bands. However, the inherent constraint of the microstrip antenna in its conventional form is its narrow impedance bandwidth of a few percent, typically 1–5% [1], which limits its new applications. Hence, the present antenna research work is mainly focused on the development of an impedance bandwidth enhancement technique for microstrip antennas. The practical techniques of bandwidth enhancement include the use of split-ring loops [4], reactive load [5], E-shaped patch [6], L-shape probe [7], parasitic patch [8], gap-coupled [9], shorting pins [10], etc. A compact millimeter wave microstrip antenna with wider bandwidth and broad beamwidth is shown to have an impedance bandwidth of 12% ($VSWR < 2.5$) [11]. However, further wideband applications require much wider impedance bandwidth, and the bandwidth of the microstrip patch antenna remains to be enhanced.

In this paper, a novel wideband multilayered microstrip antennas with shorting pins and arc-shaped apertures loaded is proposed and studied. The quasi H-shaped circular patch antenna is shown to have an enhanced impedance bandwidth ($VSWR < 2.0$) reaching 2.59 GHz (6.17–8.76 GHz), which is up to 34.7% at its centre frequency with the measured result, and is physically small and low-profile, which makes it suitable for wideband applications.

2. ANTENNA STRUCTURE AND DESIGN

In the analytical cavity model of describing the behaviour of microstrip antennas, the antenna is considered as a cavity with its two side-walls as perfect magnetic conductors and top- and bottom-walls as perfect electric conductors. Conventional microstrip antennas work at dominant modes such as TM10/TM01 modes for rectangular microstrip antennas, TM11 mode for circular/ring ones. However, it is difficult to realize a wide bandwidth of the conventional microstrip antenna operating in dominant modes only, which is due to the high Q-factor of antennas. Hence, shorting pins and arc-shaped coupling apertures loaded on the quasi H-shaped circular patch are used here to excite multiple modes due to the disturbed surface electric current on the radiation patch, which can change the cavity's electromagnetic characteristic by influencing the series-parallel connection inductance. As a result, the wide bandwidth is obtained.

The schematic graph of the proposed antenna here is shown in Fig. 1. The antenna consists of two dielectric substrates and a quasi H-shaped circular patch with five shorting pins and four arc-shaped apertures loaded on the upper layer. The F4B-2 substrate with permittivity of 2.65 is chosen as the lower substrate, and Rogers 5880



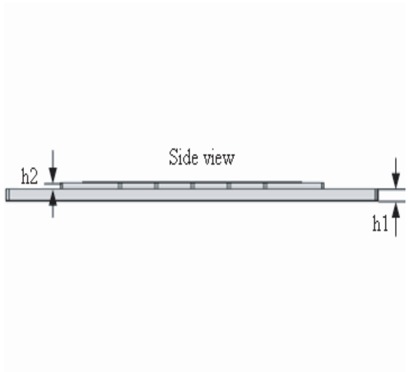


Figure 1. Schematic graph of the proposed antenna. $W_1 = 40.6$, $W_2 = 28.6$, $W_3 = 4.3$, $W_4 = 3.5$, $L_1 = 40.6$, $L_2 = 28.6$, $L_3 = 22$, $L_4 = 0.2$, $L_5 = 0.85$, $G = 0.3$, $F = 3$, $h_1 = 1.5$, $h_2 = 0.78$, $R_1 = 12$, $R_2 = 4$, $D = 0.2$, $L = 12.85$, all in mm.

substrate with permittivity of 2.2 is chosen as the upper substrate. The quasi H-shaped circular patch lies on the upper substrate, and two slots are located on the patch. Five shorting pins, which connect the radiation patch and feed line, divide the diameter of patch into six parts congruously in y-direction. Four arc-shaped apertures divide the radiation patch into five parts. The radius of bigger outer arc is R_1, and the radius of smaller one is R_2. The distance between the center of bigger arcs and origin is defined as L. The total length of the feed line is L_3. The width of the feed line which lies between the upper and lower substrates is W_4, and the width of the other part is W_3. The size of the feed line is calculated in terms of the real part of the input impedance to be as close as possible to $50\,\Omega$, over a wide frequency range possible. Copper patch is chosen as ground in the proposed antenna.

3. EFFECTS OF THE KEY PARAMETERS

As we know, shorting pins and arc-shaped coupling apertures used here can influence the series-parallel connection inductance, which can change the cavity's electromagnetic characteristic. Hence, adjusting the size of the four arc-shaped coupling apertures and five shorting pins, we can change the resonant frequency spectrum of the proposed antenna, with the aim of exciting multiple modes at the same time in the operating bandwidth. A commercially available finite-element analysis package, Ansoft HFSS, is used here to simulate and optimize this structure to achieve wide bandwidth. The following section describes the results of a study, which determines how some of the antenna parameters affect the wideband performance. Here, the following parameters are selected for this study: Shorting-pin diameter D, distance L as defined in Fig. 1, bigger outer arc radius R_1 and smaller outer arc radius R_2.

3.1. Effect of Shorting-pin Diameter D

Shorting pins with various diameters are investigated empirically to determine the effect on the performance of the antenna. Fig. 2 shows how the wideband performance is affected by varying the diameter of the shorting pins. It clearly shows that the diameter of the shorting pins can significantly influence the input impedance of the antenna and hence its resonance frequencies. By decreasing D, the impedance bandwidth of the antenna increases except the case of $D = 0.1$ mm, and three resonances also merge into two resonances when $D = 0.1$ mm. The first resonance frequency tends to shift downwards with an increase of diameter of the shorting pins. However, the frequency of the third resonance almost remains unchanged. Higher values of D decrease the input impedance matching especially at a lower resonance frequency. In Fig. 2, we can see that the best bandwidth is obtained when $D = 0.2$ mm and a diameter of $D = 0.2$ mm is chosen to provide the optimal response in terms of broadband performance.

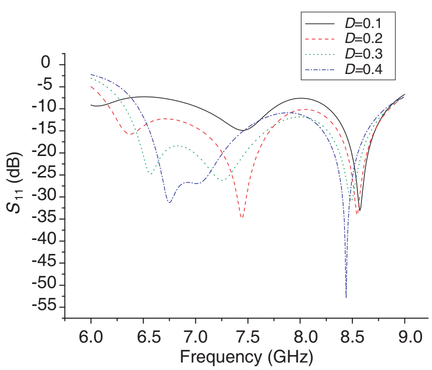


Figure 2. Return-loss as a function of different D.

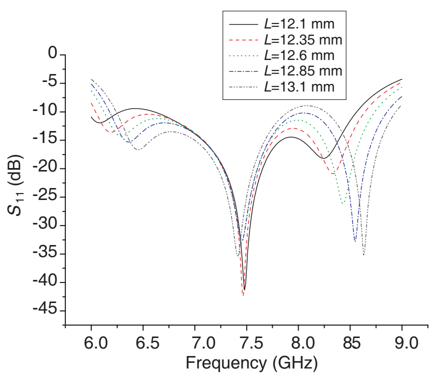


Figure 3. Return-loss as a function of distance L.

3.2. Effect of Distance *L*

The distance L between the center of bigger arcs and origin has a great effect on the performance of the antenna, as shown in Fig. 3. As the distance L increases, the first and third resonance frequencies tend to shift downwards. However, the frequency of the second resonance almost remains stationary. We can see that the best bandwidth is obtained when $L = 12.85\,\text{mm}$ in Fig. 3, so an optimum value of $L = 12.85\,\text{mm}$ is chosen for the antenna design.

3.3. Effect of Bigger Outer Arc Radius R_1

Radius R_1 is varied to fully understand its effect on the performance of the antenna. The effect of the radius R_1 on input impedance of the antenna is shown in Fig. 4. With the decrease of R_1, the first resonance frequency tends to shift downwards. The middle resonance frequency completely disappears, and the three resonance frequencies merge into two resonance frequencies when $R_1 = 10\,\text{mm}$. However, the frequency of the third resonance frequency remains nearly steady. Comparing the results of these different values, we can see that the best bandwidth appears when $R_1 = 12\,\text{mm}$. So an optimum value of $R_1 = 12\,\text{mm}$ is chosen for the antenna design.

3.4. Effect of Smaller Outer Arc Radius R_2

Figure 5 shows how the antenna response is affected by the smaller arc radius. As the smaller arc radius increases, the first resonance frequency tends to shift upwards, and the third resonance frequency

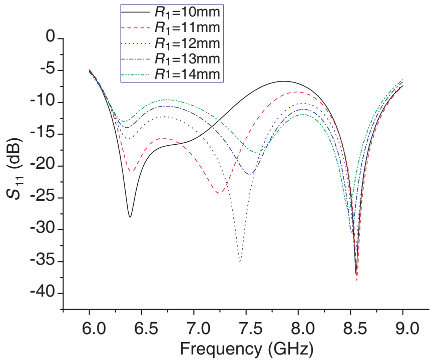


Figure 4. Return-loss as a function of radius R_1.

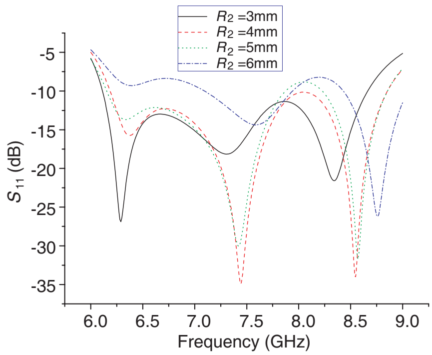


Figure 5. Return-loss as a function of radius R_2.

tends to shift right. When $R_2 = 6$ mm, the first resonance frequency almost disappears. Comparing the results of these different values, we can see that the best bandwidth appears when $R_2 = 4$ mm. So an optimum value of $R_2 = 4$ mm is chosen to provide the optimal response in terms of broadband performance.

4. SIMULATION AND MEASURED RESULTS

The proposed antenna is fabricated based on the optimum values of the parameters discussed above. The photo of the proposed antenna is shown in Fig. 6. The simulated and measured return loss of the designed antenna is shown in Fig. 7, where the impedance bandwidth reaches 2.59 GHz (6.17–8.76 GHz) ($VSWR < 2.0$) with the measured results, which means that the relative impedance bandwidth is expanded up to 34.7%. Good agreement is observed between the measured and simulated results, with the exception that the first and second resonance frequencies of the measured return loss shift upwards; the third resonance frequency shifts left; a dip in measured results appears at 8.7 GHz. Also the measured bandwidth is marginally smaller than that predicted with Ansoft HFSS. The simulated and measured results of the gain radiation patterns at 7.5 and 8.5 GHz are shown in Fig. 8 and Fig. 9 respectively. The structure of the patch antenna is symmetrical, but the whole structure which consists of the patch antenna and the microstrip feed line is not symmetrical, and the feed line always participates in the radiation. At yz-plane, due to the presence of the microstrip feed line, the whole structure is not symmetrical, so the departure of the pattern appears, and the main

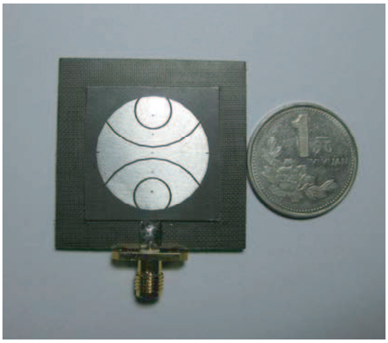


Figure 6. Photograph of proposed antenna.

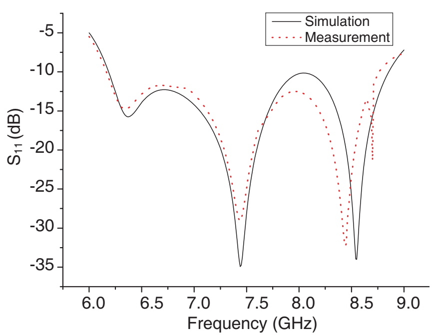
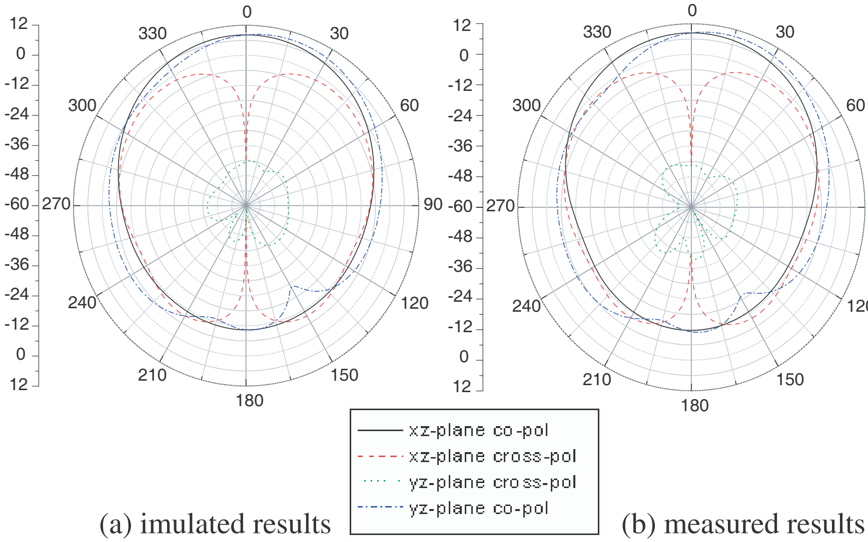
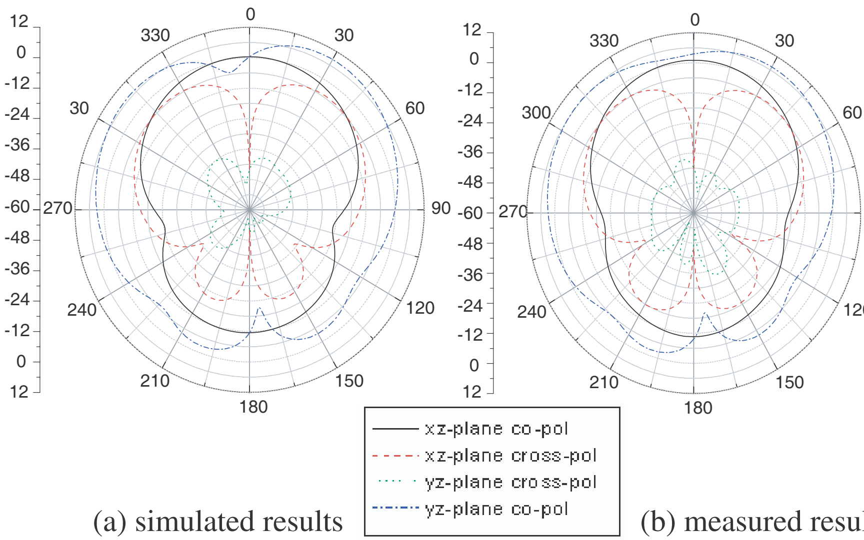


Figure 7. Simulated and measured return loss of the designed antenna.



(a) imulated results (b) measured results

Figure 8. Simulated and measured results of the gain radiation patterns at 7.5 GHz



(a) simulated results (b) measured results

Figure 9. Simulated and measured results of the gain radiation patterns at 8.5 GHz.

direction is no longer at 0 degree. The level of cross-polarization in the radiation pattern of the yz-plane is much smaller than co-polarization whereas this characteristic is not obvious in the xz-plane. This is due to the increased likelihood of exciting modes which contribute to the cross-polarization fields as a result of the discontinuity on the patch due to the presence of the shorting pins and arc-shaped apertures [12]. Regarding the experimental and simulated results of the proposed antenna, there exist some discrepancies between theoretical estimation and practical results. These discrepancies may result from the errors in the process of antenna fabrication.

5. CONCLUSION

In this paper, a novel wideband multilayered microstrip antenna with shorting pins and arc-shaped apertures loaded is designed and fabricated. The proposed antenna comprising two dielectric substrates and a quasi H-shaped circular patch with five shorting pins and four arc-shaped apertures loaded on the upper layer achieved an input impedance bandwidth of 34.7% across 6.17 GHz to 8.76 GHz. Compared with the bandwidth of 1–5% [1] of the traditional microstrip antennas as well as the bandwidth of 12% ($VSWR < 2.5$) of the improved wideband microstrip antenna proposed by [11], this novel antenna which possesses wide bandwidth of 34.7% revealed by numerical results has enhanced the bandwidth to a great extent. Also the proposed antenna is physically small and low-profile, which make it suitable for wideband applications.

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