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DESIGN OF BROADBAND COMPACT SIZE ANTENNA COMPRISED OF PRINTED PLANAR DIPOLE PAIRS

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Abstract—In this paper, a wideband planar dipole antenna is proposed. Compared to conventional dipole antennas, this antenna has wideband impedance matching, simple structure and compact size. From EM simulations, dimensions of antennas are chosen for better performance. For verification, this newly proposed structure is fabricated and measured. It is shown that return loss of the antenna between 2.5 GHz and 8.0 GHz is better than −10 dB.

1. INTRODUCTION

Compact size, low-cost printed antennas with wideband characteristic are desired in modern communications systems. Dipole antennas have been popular candidates in many systems for their various advantages, such as Light weight, low cost, ease of fabrication, etc. Normal dipole antennas are with relatively narrow bandwidth [1], about 10% for VSWR ≤ 2. This bandwidth problem has limited their application in modern wideband and multi-band communication systems. In addition, nearby objects easily detune the dipoles because of the limited bandwidth of operation.

Recently, many monopole based planar antennas have been developed for UWB communication systems [2–8]. Various planar shapes, such as square, circular, triangular, and elliptical shapes, of monopole antenna are analyzed and reported. Compared with monopole based planar antennas, the design of wideband dipole type antennas is difficult because of effect of the ground.

For expanding the bandwidth of dipole antenna, the arms are usually designed with fat wire or metal wide planar structure. Many

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designers have tried various ways to improve the structure of the traditional dipole and monopole antennas, and many valuable results have been obtained. A series fed printed strip dipole is proposed in [9]. Its bandwidth is greater than 30% for VSWR < 1.5. Ma and Jeng [10] present a tapered-slot feeding structure, curve shape dipole antenna. It may cover from 3.1 GHz to 10.6 GHz for VSWR < 2. Some other types of wideband printed dipoles (square [10], circle [12, 13], bow-tie [14, 15], and elliptical shapes [16], etc.) are presented. Mao et al. [17] introduce a wideband printed dipole which is with complex structure. Operating bandwidth of the proposed antenna reaches 47.7%. The above wideband dipole antennas are categorized as end-fire radiation antennas. The total heights of the antennas are all large. Normally, some systems require the antennas with low profile because there is not enough space to fix so many types of equipment in modern systems. To further make the antennas compact-sized and easily integrated into communication systems, a new planar dipoles antenna is proposed in this paper.

2. ANTENNA CONFIGURATION AND DESIGN

The geometry, parameters, top and side views for a prototype of the proposed planar dipole antenna are shown in Figure 1. The antenna consists of two identical printed circular arms, 50 Ω microstrip line, a probe connector and ground. Two arms of the dipole antenna are printed on the opposite sides of substrate. The planar arms parallel to x-y plane; microstrip line is along the y-axis. The inner

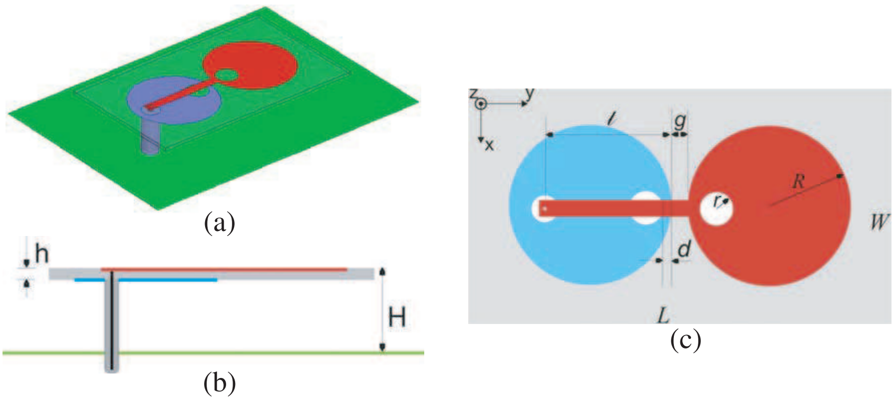


Figure 1. Configuration of the proposed antenna. (a) Three-dimensional view. (b) Cross-sectional view. (c) Top view.

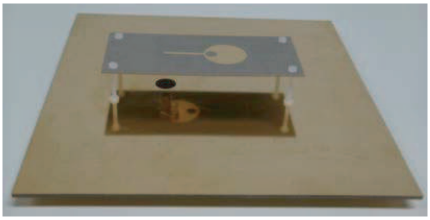


Figure 2. Photograph of the proposed antenna.

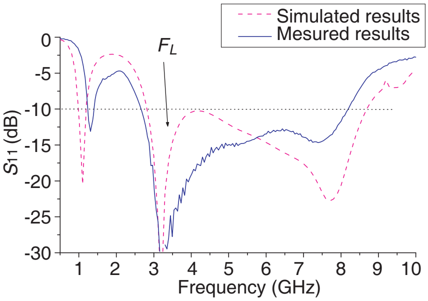


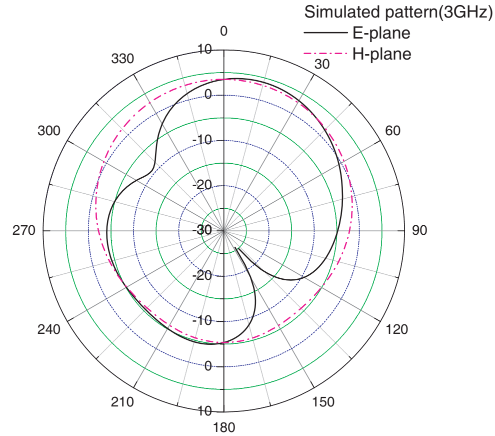
Figure 3. S_{11} of the proposed antenna.

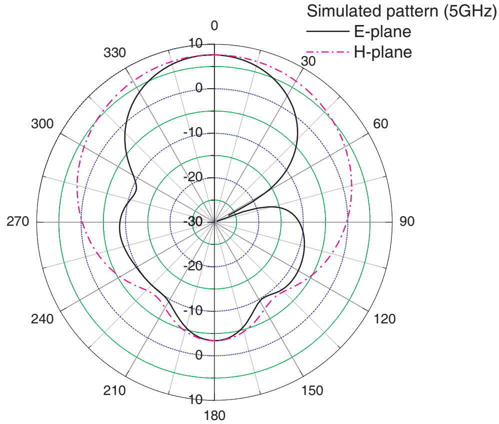
conductor of coaxial cable (or SMA connecter) connects to one arm by microstrip. The outer conductor of coaxial cable (or connector) connects to another arm (Figure 1). At the same time this arm is the ground of microstrip line. The side view of the proposed antenna looks like the capital letter "T" or inverse "L", we call this class antenna as "TL" antenna for easy identification. In Figure 1, the arms of dipole antenna is circular shape. The arms may also be designed with different shapes, such as elliptical, square, hybrid elliptical/square, triangular shapes, etc. After these different shape antennas are studied, we found circular, elliptical, hybrid elliptical/rectangular shape antennas have wider VSWR bandwidth. The circular shape antenna is selected for demonstrating the proposed antenna in this paper.

The radius of circular arm is R. Both arms have small circular cuts, with radii r. The width of microstrip line is w for 50 Ω. There is a gap between two arms, with a distance g in top-view. The substrate is with depth h and permittivity ε_r. From the top of the substrate to the bottom ground, the distance is H. The length of feed line is l. The feed line connects to the upper arm.

3. NUMERICAL ANALYSIS AND DISCUSSION

To analyze impedance and bandwidth, the proposed antenna was first simulated by the EM full-wave simulator HFSS version 10 and then fabricated on a Rogers RT/Duroid 5880 TM substrate of a dielectric constant ε_r of 2.2, conductor loss ($\tan\delta$) of 0.0009 and thickness of 0.787 mm.


Simulated pattern(3GHz)
E-plane
H-plane
0
30
60
90
120
150
180
210
240
270
300
330
10
0
-10
-20
-30


Simulated pattern (5GHz)
E-plane
H-plane
0
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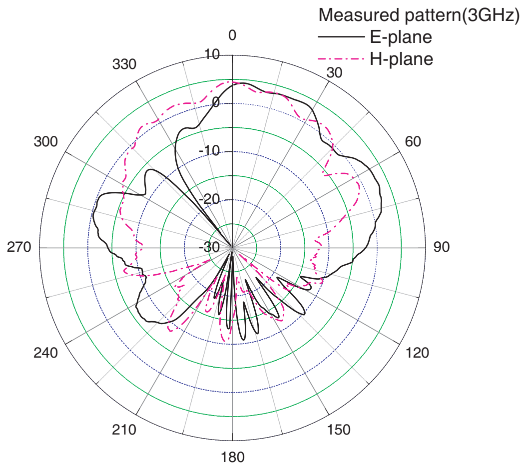
60
90
120
150
180
210
240
270
300
330
10
0
-10
-20
-30


Measured pattern(3GHz)
E-plane
H-plane
0
30
60
90
120
150
180
210
240
270
300
330
10
0
-10
-20
-30

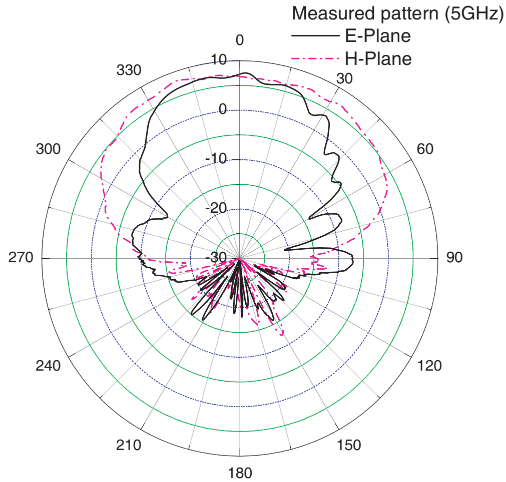


Figure 4. Radiation patterns of the antenna.

3.1. Design of Single Element

The optimized parameters of circular dipole antenna in accordance with the design considerations in Section 2 are given as follows: $R = 10\,\text{mm}$, $H = 20.0\,\text{mm}$, $r = 2.5\text{mm}$, $w = 2.2\,\text{mm}$, $g = 1.0\,\text{mm}$, $l = 16.4\,\text{mm}$, $d = 1.0\,\text{mm}$, $W = 40\,\text{mm}$, $L = 90\,\text{mm}$. A photograph of the fabricated antenna is shown in Figure 2. The circular dipole which is printed on the substrate is fixed with plastic posts above the ground. The size of ground is 150 mm by 150 mm.

The measurement was taken using the Agilent E8362B network analyzer. The simulated and measured results are shown in Figure 3. A good agreement between measured and computed results is noticed. The impedance bandwidth of the proposed antenna with S_{11} better than $-10\,\text{dB}$ covers a very wide frequency ranging from 2.5 GHz to more than 8.0 GHz. The difference between simulated and measured results comes from the SMA connector. The coaxial cable of the HFSS modeling traverses the bottom ground, but the connection between the cable and ground is not good when the measurement was done. Another reason is that the metal is zero thickness in the simulated modeling, but the fabricated one is not.

It is shown that both measured and the simulated curves are with three pits in Figure 3. It illuminates that the proposed antenna has three different modes, one due to inverted L structure (resonance at 1.1 GHz regarding as simulated data), the second due to dipole mode (around at 3.2 GHz), and the third due to disk loaded monopole mode

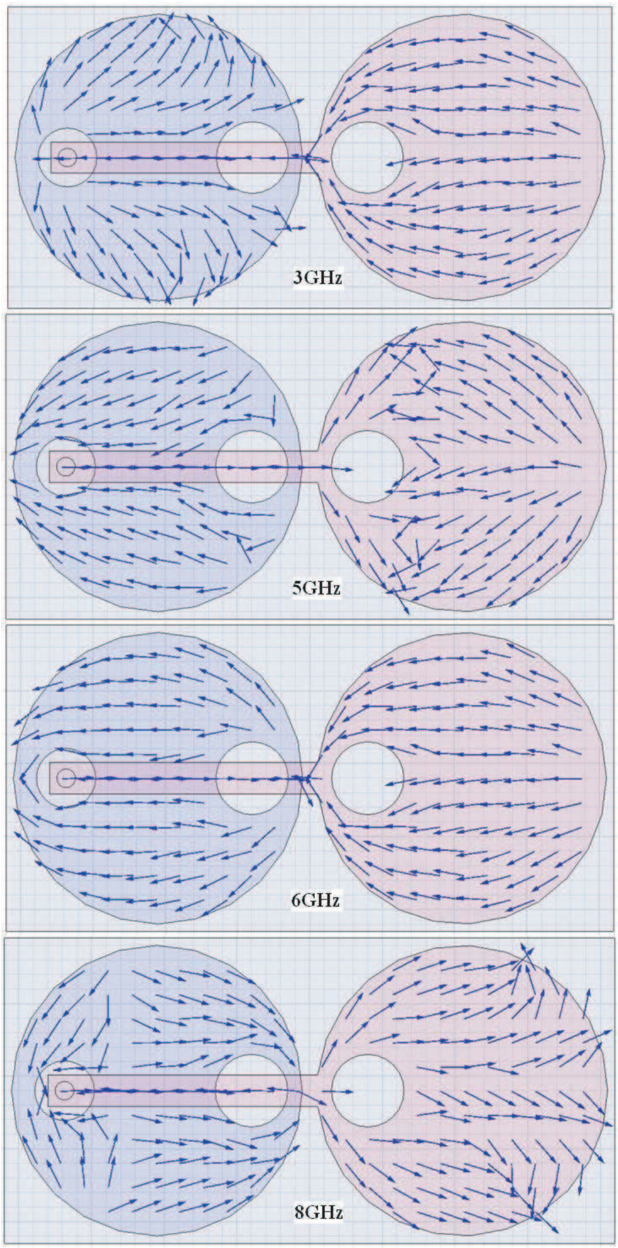


Figure 5. The currents on the surface of the antenna at 6 and 8 GHz.

(around at 7.8 GHz).

The frequency operating range is mainly determined by adjusting the value of R. The low frequency F_L is roughly evaluated:

$$F_L = \frac{300}{2\,(4R + g)} \text{ (GHz)} \tag{1}$$

Length unit is in mm. The effect of other geometric parameters (such as l and d) on the frequency range is not patency.

The simulated and measured radiation patterns are shown in Figure 4. It should be illuminated: when $\phi = 0°$, θ varies from 0° to 360° (x-z plane); E_ϕ implies main polarization pattern (H-plane). Also, when $\phi = 90°$, θ varies from 0° to 360° (y-z plane); E_θ implies main polarization pattern (E-plane). The simulated radiation patterns

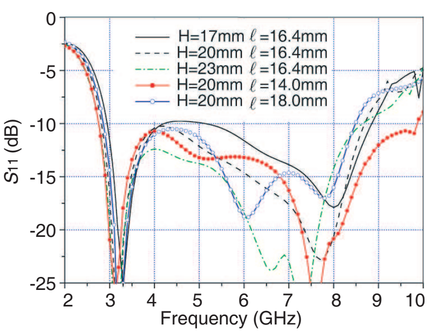


Figure 6. Return loss of the proposed antennas, varying H and l.

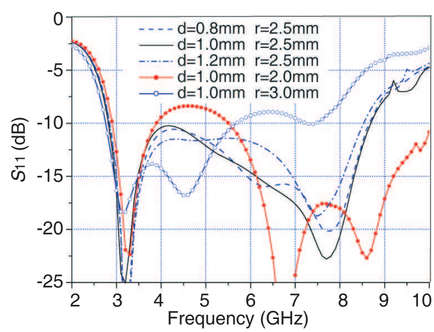


Figure 7. Return loss of the proposed antennas, varying r and d.

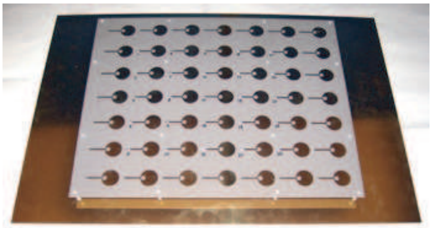


Figure 8. Photograph of the antenna array with circular dipole elements.

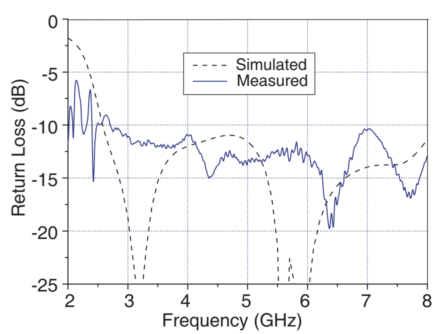


Figure 9. Return loss of center element in the array.

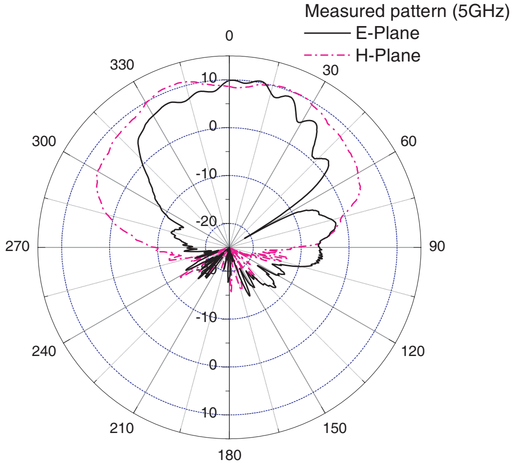


Figure 10. Radiation patterns of center element in 3 × 3 array.

are not presented here. The E-plane pattern of the antenna is not symmetrical at 3 GHz, the reason is the unbalun currents on the circle arms are too strong around the resonant frequency. The shape of E-plane pattern is symmetrical when the frequency is higher than 3.5 GHz.

3.2. Analysis of Single Element Antenna

Frequency operation range of the proposed antenna was determined by the radius (R) of circular arm. It can be approximately evaluated using Equation (1). The other geometric parameters will affect the antenna's performance over the whole frequency band. H is selected around quarter wavelength of F_L. The parameters r and d influence the impedance sensitively over the frequency band. The circularcut structure of the antenna arms is important to adjusting the return loss.

At first, the current distribution on the surface of dipole at low frequency (3 GHz), center frequency (5 GHz, 6 GHz) and higher frequency (8 GHz) is considered. It is presented in Figure 5. At 3 GHz, the length of circular arm is about quarter wavelength. The length combining feed strip and circular arm dipole is about half wavelength. It induces the currents on the bottom circular patch are in the inverse direction. Because the unbalanced distribution of the currents, the radiation pattern is not symmetrical at 3 GHz. At 6 GHz, the length of circle dipole is around half wavelength. The currents on both circle patches are in the same direction. The currents are non-regular at 8 GHz. The non-regular currents distribution will result in the poorer radiation pattern at the boresight.

Based on the optimized parameters of circular dipole antenna presented above, the effects of H, l, r, and d are studied. Figure 6 shows the return loss with different values of H and l. Simulated results indicate that H has no severe impact on the frequency response; l mainly controls the upper band cut-off frequency due to the 3rd mode excitation control. It is also observed that small value of H (17 mm) has better radiation pattern at 8 GHz, but it will bring on difficult matching at the center frequency range, from 4 GHz to 6 GHz. Considering the size and electric performance, $H = 20$ mm and $l = 16.4$ mm are selected for fabrication.

The simulated results for varying r and d are shown in Figure 7. The results indicate that the return loss varies slowly with d. But the curves vary fast with r. The impedance is sensitive to parameters r. By adjusting the value of r, better matching impedance will be reached over wideband. The best choice of the parameters is: $r = 2.5$ mm and $d = 1.0$ mm.

3.3. Performance of Antenna Element in Array

Because of the limitation of computer memory, only a 3×3 array with circular dipole elements is simulated. The grid distances between elements are 37 mm in column (H-direction) and 44 mm in row (E-direction), respectively. Based on the small array, a 7×7 antenna array is designed and fabricated. The photograph of the antenna array is shown in Figure 8. The simulated return loss of center element is shown in Figure 9. For comparison, the measured results of the element are located at the third column, and the third row is also presented in Figure 9. The elements located at borders are not connected with connector. All the other elements are connected with 50 Ω loads. Both the simulated and measured results verify that the proposed antenna element works very well in the array surroundings. The performances of both impedance and radiation are good over the whole frequency band. It implies that the new proposed antenna has good performance when it is employed as an array element. The radiation patterns of center element in the 3×3 array at 5 GHz are presented in Figure 10.

4. CONCLUSION

A novel planar fat dipole antenna has been presented. These antennas are with wide frequency bandwidth and compact size. Several simulation results are carried out, and the properties of the antennas are presented. Some prototype fat dipole antennas are fabricated and measured. Measurement and simulation show that the advantages of easy feed implementation and better impedance matching. It is expected that the antenna has proper properties for wideband applications.

This type antenna has 100% impedance bandwidth. It provides low cross polarization level and relatively high gain in the frequency range from 2.5 GHz to 8.0 GHz. Furthermore, the radiation direction is in the vertical plane of planar dipole; the thickness of the antenna is smaller than the endfire radiation antenna. The proposed antenna has good performance in array surroundings. A stable radiation pattern and wide usable bandwidth of the array are obtained using these types of dipole elements.

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