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A WIDEBAND WIDE-STRIP DIPOLE ANTENNA FOR CIRCULARLY POLARIZED WAVE OPERATIONS

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Abstract—A thin dipole antenna is a well-known antenna with linearly polarized wave operation. In this work, a wide-strip dipole antenna is proposed for circularly polarized wave operations. To obtain circularly polarized (CP) wave operations, there are two conditions to be satisfied. One is that the antenna must have two degenerated orthogonal modes with different resonant frequencies. The other is that the phase difference of two orthogonal modes is 90 degrees. To match the first condition, the slab width W is tuned to generate current distributions directed in two different directions. In addition, the second condition is matched by asymmetric feeding point by adjusting the overlapped square width C. The parametric study is completed by the Ansoft HFSS simulator. Simulated results reveal that the CP wave is mainly influenced by the slab width W. The influences of the parameters C and d on the performances of the proposed antenna are also investigated in this paper. Taking -8 dB as reference, there are two working bands for this proposed antenna and the measured center frequencies are 0.66 GHz and 2.04 GHz, respectively, and the corresponding bandwidths are 0.27 GHz (40%) and 1.78 GHz (87%), respectively. In addition, the measured center frequencies and bandwidths of the axial ratio are 1.94 GHz and 0.53 GHz (27%), respectively.

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1. INTRODUCTION

Generally, a balanced-fed strip dipole antenna or monopole antenna owns the linear polarization, omni-directional radiation pattern in the H-plane, and about 2 dBi antenna gain. It has been used widely in the consumer products for its good characteristics and low cost. Such facts have been comprehensively reported by some papers [1–10]. On the other hand, the circularly polarized (CP) antennas applied to the modern communication become more and more popular not only in the satellite communication but also in the territorial communications. Moreover, antennas with circular polarization can be used in radio frequency identification (RFID) systems and global positioning system (GPS) to reduce power loss resulted from polarization mismatch. To obtain circularly polarized wave operations, there are two conditions to be satisfied. One is that the antenna must have two degenerated orthogonal modes with different resonant frequencies. The other is that the phase difference of two orthogonal modes is 90 degrees. The often utilized technique to generate CP wave in the microstrip antenna is feeding asymmetrically in the microstrip patch to generate two degenerated modes and to complete impedance matching [11–20]. However, it is impossible to generate a circularly polarized wave in a single dipole antenna because only z-directed current distribution exists on the thin cylindrical conductor.

In recent, some papers [21–23] try to introduce circularly polarized radiation by modifying the conventional dipole antenna. Two dipoles [21, 22] are fed by two transmission lines, individually, with a ninety-degree phase difference and the same amplitude to produce the circular polarization property. In paper [23], the circularly polarized operation is achieved by combining a dipole antenna with an artificial ground plane. In addition, the C-type feeding technique [24, 25] is a useful technique for improving the axial ratio bandwith and quality of CP stacked microstrip antennas. However, to the authors' best knowledge, only a few attempts have so far been made to generate circularly polarized wave by modifying the conventional thin dipole antenna. In this paper, the authors try to modify the original strip dipole by increasing the width of the strip and observe the behavior of polarization. The purpose of this process is to generate two different directed current distributions, which are perpendicular to each other. Finally, the authors find that a wide-strip dipole antenna can generate the circular polarization characteristics. Although a wide-strip dipole antenna can generate the circularly polarized wave, we want to analyze and explain the reason of it by the current distributions in the wide-strip metal. Just for balanced feed, only one strip's current distribution is observed. The current distribution can be divided into two parts; one is in the x-direction and the other is in the y-direction. Owing to the asymmetric feed point in the wide strip, this antenna can radiate circularly polarized wave.

2. ANTENNA CONFIGURATIONS

A strip dipole antenna with two symmetric strips is shown in Fig. 1. The length (in the x-direction) and width (in the y-direction) of the strip are L and W, respectively. There is a gap d (in the z-direction) between two strips and the overlap dimensions between two strips in the x- and y-directions are both C. The Ansoft HFSS high frequency simulator based on the finite element method is used as the simulation tool. Gap source is arranged between two overlap regions. The feeding point is at the center of the overlap region. From the point of view of simulation, the antenna configuration with a gap source is a symmetrical structure. It has a symmetrical radiation patterns. But in

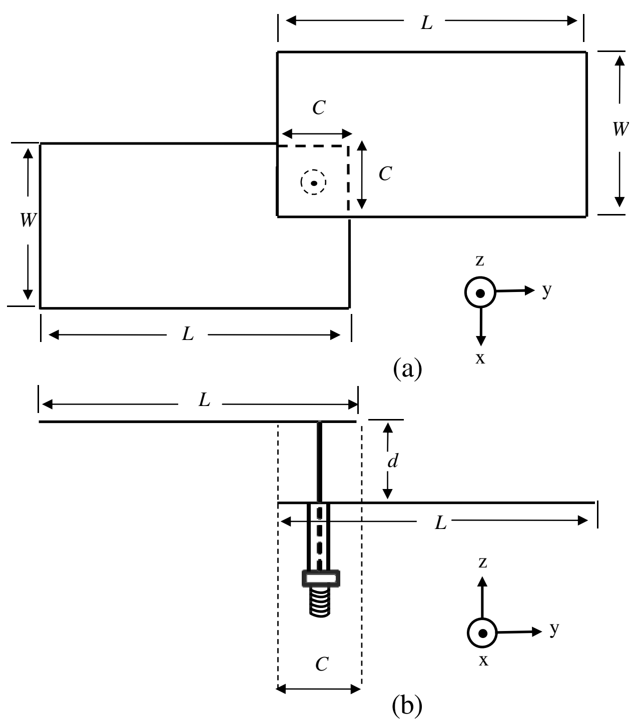

Figure 1. Geometrical configuration of a wideband wide-strip dipole antenna for circularly polarized wave operations: (a) Top view; (b) side view.

the real sample, a coaxial cable is needed to feed the RF power into the two strips. Hence, a rigid mini-coaxial cable with a radius of 0.6 mm is adopted to feed into the two strips. And then, one strip is connected to the inner conductor of the cable, and the other strip is connected to the outer conductor of the cable. Although the real sample is not a good balanced feed, the results of the reflection coefficient and axial ratio as well as the radiation patterns match well with those of the simulation data.

3. RESULTS

3.1. Reflection Coefficient

After the optimization of the antenna parameters, the optimal data for this structure are: $L = 100$ mm, $W = 50$ mm, $d = 10$ mm, $C = 15$ mm, respectively. The measured and simulated reflection coefficients are shown in Fig. 2. Taking -8 dB as reference, there are two working bands for this proposed antenna and the measured center frequencies are 0.66 GHz and 2.04 GHz, respectively, and the corresponding bandwidths are 0.27 GHz (40%) and 1.78 GHz (87%), respectively. In addition, the simulated center frequencies are 0.68 GHz and 2.02 GHz, respectively, and the corresponding bandwidths are 0.23 GHz (33%) and 1.75 GHz (86%), respectively. Both simulated and measured reflection coefficients are in good consistency and the wide impedance bandwidth is achieved in this proposed antenna. As shown in Fig. 2, it seems that there exist multi bands in this proposed

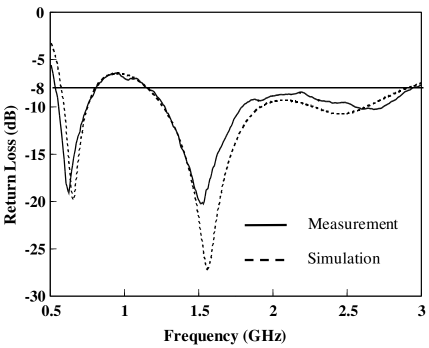

Figure 2. Measured and simulated return loss of the proposed wide strip dipole antenna with parameters: $L = 100$ mm, $W = 50$ mm, $d = 10$ mm, and $C = 15$ mm.

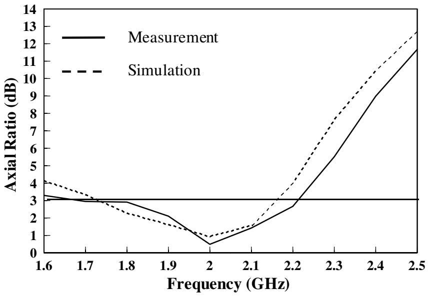

Figure 3. Measured and simulated axial ratios of the proposed wide strip dipole antenna with the same parameters in Fig. 2.

antenna. This fact results from the reason that there are multiple current paths in the wide strip.

3.2. Axial Ratio

To verify whether or not the proposed antenna can radiate circularly polarized wave, the axial ratios (AR) in the z-direction for the simulated and measured data are illustrated in Fig. 3. As shown in this figure, taking 3 dB as reference, the measured and simulated center frequencies are 1.940 GHz and 1.945 GHz, respectively, and the corresponding AR's bandwidths are 0.53 GHz (27%) and 0.44 GHz (23%), respectively. Both simulated and measured axial ratios match well and the proposed antenna is a wide-AR bandwidth antenna due to the 27% axial ratio bandwidth. Hence, the proposed antenna owns both wide impedance and wide axial ratio bandwidths. As shown in Fig. 3, the proposed antenna can radiate circularly polarized wave in the z-direction. To realize the circularly polarized characteristics in different angles, the simulated axial ratios at 1.94 GHz in the x-z and y-z plane are shown in Fig. 4. Taking 3 dB as reference, the circularly polarized wave ranges from -18 degrees to 60 degrees and from -132 degrees to 160 degrees in the x-z plane. Moreover, the circularly polarized wave ranges from -16 degrees to 14 degrees and from -168 degrees to 162 degrees in the y-z plane. Owing to large acceptable angles for circularly polarized radiation, this proposed antenna is suitable for circularly polarized operation.

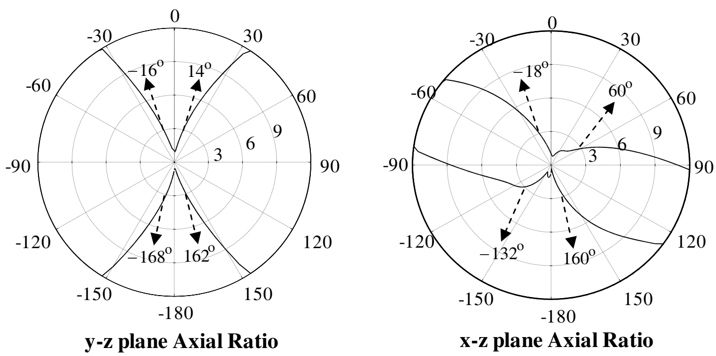

Figure 4. Simulated axial ratios of the proposed wide strip dipole antenna at 1.94 GHz.

3.3. Radiation Patterns

The measured and simulated radiation patterns at 1.94 GHz in the y-z and x-z plane are shown in Fig. 5 and Fig. 6, respectively. To observe the circularly polarized radiation, the radiation patterns are divided into a right-hand circularly polarized (RHCP) wave and a left-hand circularly polarized (LHCP) wave. The two figures indicate that the forward radiation is dominated by LHCP and the backward radiation is dominated by RHCP, respectively.

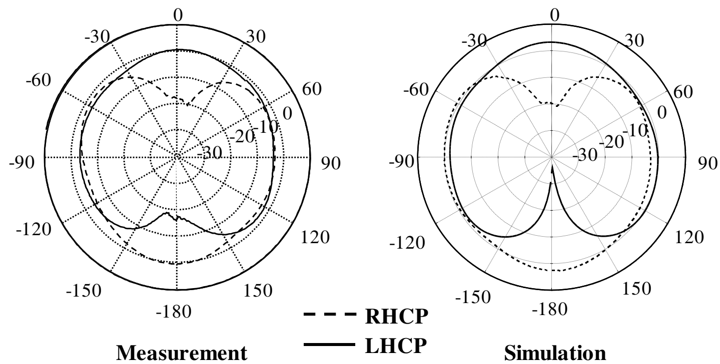

Figure 5. Measured and simulated y-z plane radiation patterns of the proposed wide strip dipole antenna at 1.94 GHz.

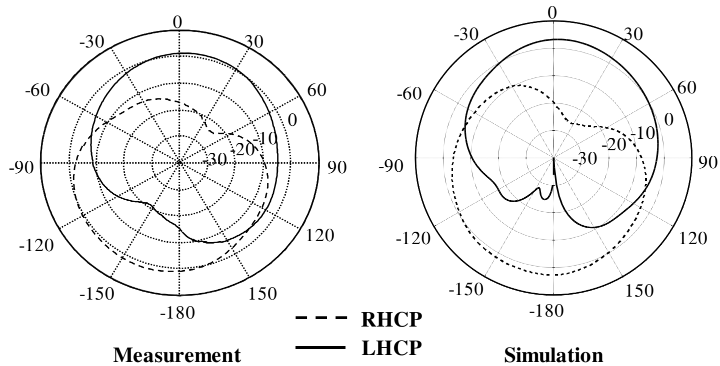

Figure 6. Measured and simulated x-z plane radiation patterns of the proposed wide strip dipole antenna.

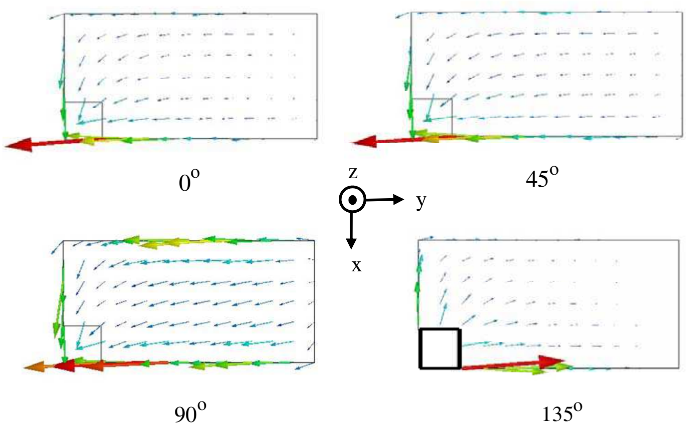

Figure 7. Current distributions at 0.65 GHz.

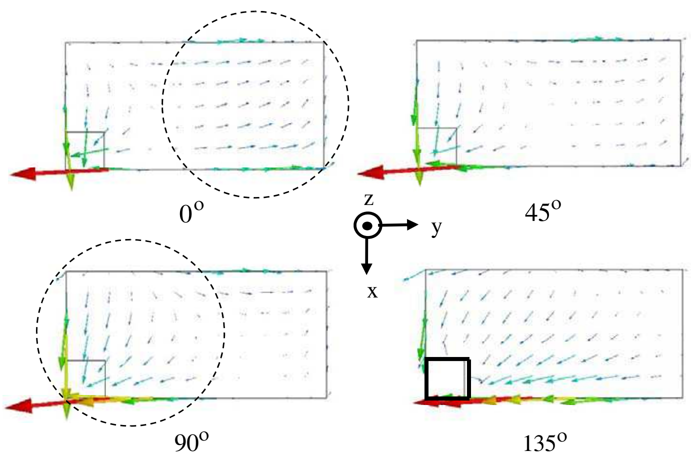

Figure 8. Current distributions at 1.94 GHz.

3.4. Current Distributions

In order to analyze why the proposed antenna has the circular polarization characteristics, the current distributions in only one metal strip at 0.65 GHz and 1.94 GHz are plotted in Fig. 7 and Fig. 8, respectively. As shown in Fig. 7, most of the current distributions are directed in the y direction for four different phase angles $\omega t = 0°$, $45°$, $90°$, and $135°$, respectively. Hence, the proposed antenna generates linearly polarized radiation in the lower frequency 0.65 GHz. However, at $\omega t = 0°$ as shown in Fig. 8 for the upper frequency 1.94 GHz, the current distributions can be divided into two major parts: one is the x-directional current flowing in the center strip to the end, and the other is the y-direction current flowing from the feeding point to the end of width in the upper region. But the dominant current distribution is directed in the x direction. The equivalent length of the current trace in the x-direction seems to be a half wavelength and that in the y-direction to be a quarter wavelength. At $\omega t = 45^\circ$, the current distributions revealed in Fig. 8 obviously own two dominant parts. However, the current distributions at $\omega t = 90^\circ$ shown in Fig. 8 are dominant in the y-direction. Hence, Fig. 8 demonstrates that the currents are dominant in orthogonal current's direction with phase difference of ninety degrees. As a consequence, the circular polarized wave will be generated to propagate into free space. Generally, the circularly polarized wave can be divided into two types: one is resonance mode and the other is traveling-wave type. The proposed antenna can be judged as the resonant type. It has two resonance modes: one is half-wavelength resonance mode and the other is a quarter-wavelength mode. Hence, the concept of CP with two resonance modes (one is half-wavelength and the other is quarter-wavelength) will give the antenna designer a very clear idea to design the wide-strip dipole antenna with CP characteristics. As shown in Fig. 8, it is obvious that the currents at any point in the metal strip rotate clockwise so that the forward radiation is dominated by LHCP and the backward radiation is dominated by RHCP (see Section 3.3).

4. PARAMETRIC STUDY AND ANALYSIS

4.1. The Influences of the Slab Width W

Although we have known the concept of how to generate the CP wave in the proposed antenna, we still need to study and analyze the influences of the antenna parameters (such as the width and length of the strip, the feeding point, and the overlap between both metal strips) on the antenna characteristics such as impedance bandwidth and AR bandwidth. The parametric study is completed by the Ansoft HFSS simulator. Firstly, the same parameters are taken as those in Fig. 2 except the parameter W. If the slab width W is increased, the return loss shown in Fig. 9 is improved, which imply the better impedance matching is obtained. In addition, Fig. 10 indicates that the increasing of the slab width W results in the circularly polarized radiation. The conventional dipole antenna can be regarded as a special case of the proposed antenna if the slab width W is approaching zero. The conventional dipole antenna radiates linearly polarized wave, because the current distributions on the conductor are only directed in a single direction. However, there are two orthogonal current components on the proposed antenna and the circularly polarized wave can be obtained by increasing the slab width W. Moreover, the performances of different slab width W are shown in Table 1. The symbol "NA" in the Table 1 denotes that the axial-ratios are greater than 3 dB for all frequencies.

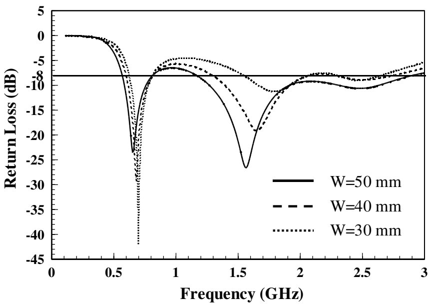

Figure 9. Simulated return loss for different slab width W.

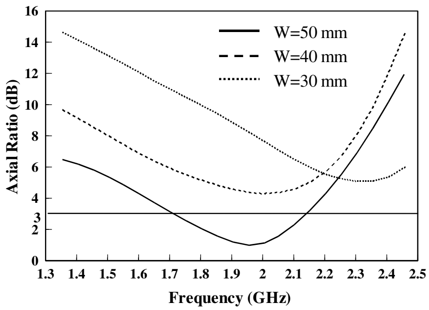

Figure 10. Simulated axial ratios for different slab width W.

Table 1. The performances of the proposed antenna in the variation of the parameter W.

W (mm)	AR Bandwidth (MHz)	AR Center Frequency (GHz)	Bandwidth (%)
30	NA	NA	NA
40	NA	NA	NA
50	440	1.94	23

Table 2. The performances of the proposed antenna in the variation of the parameter C.

C (mm)	AR Bandwidth (MHz)	AR Center Frequency (GHz)	Bandwidth (%)
5	560	1.9	29.4
10	500	1.93	25.9
15	440	1.94	22.68

4.2. The Influences of the Overlapped Square Width C

In this subsection, the same parameters are taken as those in Fig. 2 except the parameter C. As shown in Fig. 11, the impedance matching is improved if the overlapped square width C is increased. In addition, Fig. 12 and Table 2 indicate that the increasing of the overlapped square width C has little influence on the axial ratio.

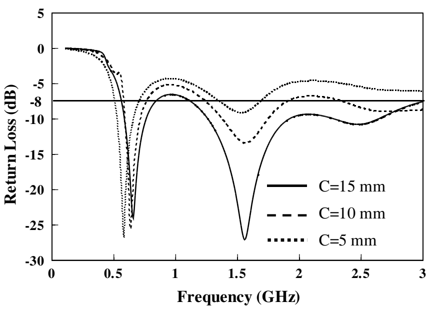

Figure 11. Simulated return loss for different overlapped square width C.

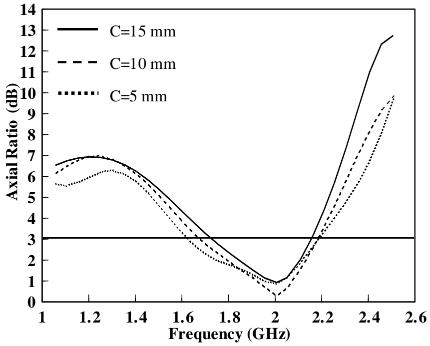

Figure 12. Simulated axial ratios for different overlapped square width C.

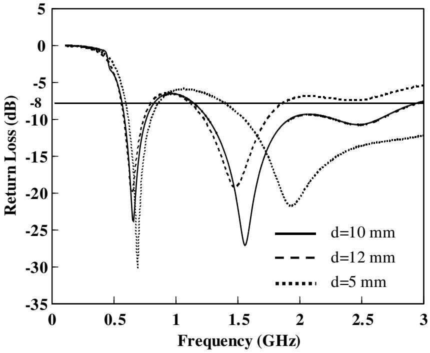

Figure 13. Simulated return loss for different port length d.

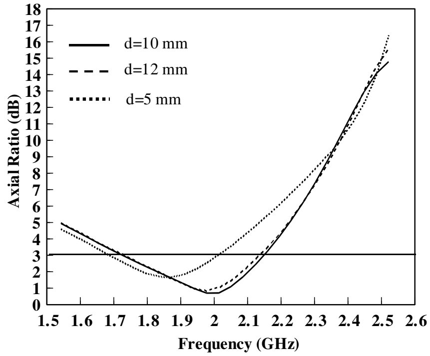

Figure 14. Simulated axial ratios for different port length d.

4.3. The Influences of the Port Length d

In this subsection, the same parameters are taken as those in Fig. 2 except the parameter d. As shown in Fig. 13, the port length d can be

Table 3. The performances of the proposed antenna in the variation of the parameter d.

d (mm)	AR Bandwidth (MHz)	AR Center Frequency (GHz)	Bandwidth (%)
5	340	1.85	18
10	440	1.94	23
12	420	1.93	22

tuned to improve the impedance matching. In addition, Fig. 14 and Table 3 indicate that the increasing of the port length d can widen the AR's bandwidth.

5. CONCLUSION

Thin dipole antenna is a well-known antenna with linearly polarized wave operations. In this paper, a wide-strip dipole antenna is proposed for circularly polarized wave operations. To obtain circularly polarized wave operations, there are two conditions to be satisfied. One is that the antenna must have two degenerated orthogonal modes with different resonant frequencies. The other is that the phase difference of two orthogonal modes is 90 degrees. To match the first condition, the slab width W is tuned to generate current distributions directed in two different directions. In addition, the second condition is matched by asymmetric feeding point by adjusting the overlapped square width C.

The parametric study is completed by the Ansoft HFSS simulator. Simulated results reveal that the CP wave is mainly influenced by the slab width W. The studies of parameters C and d are also invested in this paper. There are two working bands for this proposed antenna and the measured center frequencies are 0.66 GHz and 2.04 GHz, respectively, and the corresponding bandwidths are 0.27 GHz (40%) and 1.78 GHz (87%), respectively. In addition, the measured center frequencies and bandwidth of axial ratios are 1.94 GHz and 0.53 GHz (27%), respectively.

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