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METHOD FOR BROADENING THE BEAMWIDTHS OF CROSSED DIPOLES FOR WIDEBAND MARINE GPS APPLICATIONS

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Abstract—In this paper, a method to broaden the beamwidths of a crossed dipole antenna is proposed. By introducing four parasitic strips around the crossed dipole antenna, the beamwidths of the crossed dipole antenna in the vertical plane are broadened effectively, making the patterns uniform over a wide frequency band. An L-band prototype, operating in the frequency range 1.1 GHz to 1.6 GHz, is fabricated and tested. The simulated and measured results show that the beamwidths at lower frequencies are broadened and uniform radiation patterns over the whole operating frequency band are obtained, making the crossed dipole suitable for wideband marine GPS (Global Positioning System) applications.

1. INTRODUCTION

Global Positioning System (GPS), which is one of the most important tools, has been widely used for providing exact information of position and time for users, especially for users in marine applications such as marine surveying and offshore exploration [1–5]. Compared with the applications on land, the applications on sea are more severe for GPS antenna designs. This is due to the fact that the ship swings with sea waves continuously. If the antenna has a narrow beamwidth and is fixed on the ship, it may be difficult for the antenna to illuminate the GPS satellites in all tilting states along with the ship swing efficiently.

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For solving this problem, mechanically steered antennas and phased array antennas have been proposed and studied [6, 7, 18]. In [6], a mechanically steerable antenna was designed by using an adjustable phase shifter, and the phase shifter employs a dielectric slab placed close to a coplanar transmission line. In [7, 18], a phased array antenna, composed of lots of radiating elements and each with a phase shifter, is proposed. By shifting the phase of the signal emitted from each radiating element, steered beams in the desired directions are implemented [6]. These antennas are usually expensive and complex owing to the use of tuning devices. However, if the antenna has broad beamwidths sufficiently covering the GPS satellites, the antenna system can be simplified and the cost can be lowered, which is desirable for most of the inexpensive marine applications.

Crossed dipole antenna is one of the most widely used GPS antennas [14, 19, 21]. To expand the impedance bandwidth, planar crossed dipole antennas have been proposed and studied [8, 10–13]. By using the planar structure, the crossed dipole antenna can produce a wide impedance bandwidth. But the formations of the radiation patterns in the vertical plane have obvious discrepancies over the wide operating frequency band, i.e., the radiation patterns are non-uniform versus frequency (the patterns at the lower frequencies are usually narrower than those at the higher frequencies) [9]. It is reasonable to assume that the non-uniform radiation patterns are not desirable for the GPS applications in the whole frequency bands [14, 20]. In this paper, a method to broaden the beamwidths of a crossed dipole antenna is proposed. By introducing four parasitic strips around the crossed dipole antenna, the beamwidths of the crossed dipole antenna in the vertical plane are broadened effectively, making the patterns uniform over the whole GPS frequency bands available. An L-band prototype, operating in the frequency range from 1.1 GHz to 1.6 GHz and suitable for wideband marine GPS applications, is fabricated and tested. The simulated and measured results are given and discussed.

2. ANTENNA DESIGN

Figure 1 shows the side view and top view of the proposed antenna, along with its coordinate system and design parameters. The main radiating element of the antenna is a crossed dipole antenna located at the center. Four metal strips, referred to as the parasitic strips herein, are introduced and arranged uniformly along a circle with a radius r_s around the crossed dipole antenna. The parasitic strips are located just under the four arms of the crossed dipole antenna. Balun structures are connected to the crossed dipole antenna, which mainly consists of

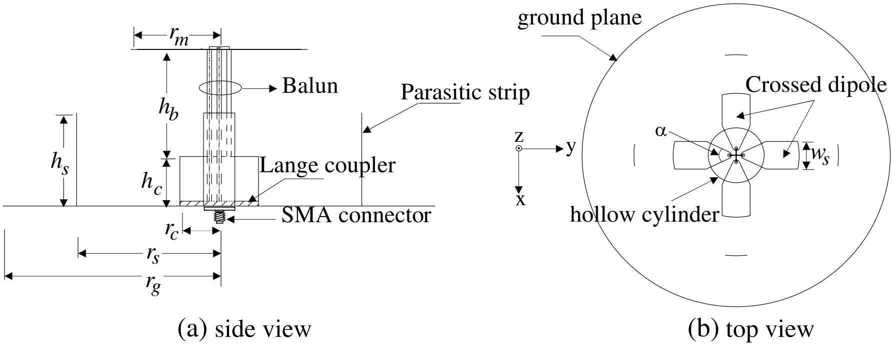

Figure 1. The geometry of the proposed antenna.

two couple of $\lambda/4$ Baluns, and each Balun consists of a copper rod and a semi-rigid coaxial cable and is connected to its related dipole. To realize circularly-polarized radiation, a quadrature-phase feeding network is usually needed for the crossed dipole antenna. In our study, a Lange coupler is chosen to feed the crossed dipole antenna because of its equal amplitudes and quadrature phases across a wide frequency band, which is installed in a hollow copper cylinder. The hollow copper cylinder acts as not only a shielding for the Lange coupler but also a supporter for the Balun and the crossed dipole antenna. Details of the operation of the Balun and Lange coupler are beyond the purpose of this paper and can be found in [8, 15, 16]. All of the abovementioned elements are mounted on a metal plate of radius r_g, which is the ground plane for the proposed antenna.

It should be noted that the four parasitic strips are introduced, as a significant way of broadening the radiation patterns of the crossed dipole antenna. The radiation characteristics of a single parasitic strip described above is similar to that of a monopole antenna. Part of the energy radiated by the crossed dipole antenna can be coupled to the parasitic strips. Hence parasitic currents are excited on the parasitic strips. The parasitic strips can radiate patterns to fill in the E-plane nulls or weak areas of the crossed dipole antenna, and this action leads to broaden the radiation patterns of the crossed dipole antenna. Each parasitic strip has a size of $h_s \times w_s$, where h_s is the height of the strip and r_s is the distance from the center of the ground. Variations of h_s and r_s strongly influences the magnitudes and phases of the excited currents on the parasitic strips, changing the radiation patterns of the crossed dipole antenna correspondingly. The dimensions of h_s and r_s can be adjusted and optimized by means of any electromagnetic simulation software, as demonstrated in the following section.

3. SIMULATED AND MEASURED RESULTS

A prototype of the proposed antenna, with $r_m = 40\,\text{mm}$, $\alpha = 50°$, $h_b = 54\,\text{mm}$, $h_c = 25\,\text{mm}$, $r_c = 20\,\text{mm}$, $h_s = 47\,\text{mm}$, $r_s = 73\,\text{mm}$, $w_s = 15.92\,\text{mm}$, $r_g = 110\,\text{mm}$ was designed and constructed to operate in the frequency band from 1.1 GHz to 1.6 GHz. A photograph of the prototype is given in Figure 2. The crossed dipole and hollow cylinder were fabricated with copper plates of thickness 0.2 mm. The ground plane and parasitic strips were fabricated with brass plates of thickness 0.5 mm. Copper rods of radius 1.0 mm and semi-rigid coaxial cable of radius 1.05 mm were used to fabricate the Balun structures.

Numerical analysis of the prototype was carried out by using the Ansoft simulation software HFSS [17]. The dimensions of the prototype, especially h_s and r_s, were designed and optimized based on HFSS simulations.

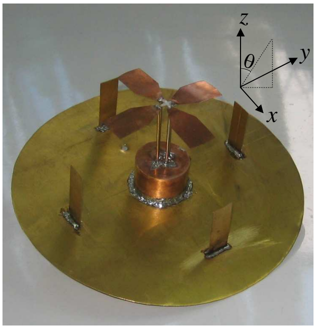

Figure 2. The photograph of the prototype in the design.

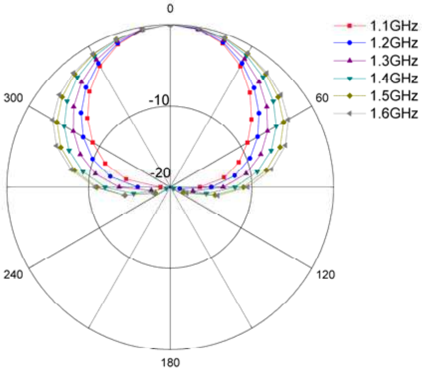

Figure 3. Simulated RHCP patterns of the fabricated crossed dipole antenna without parasitic strips.

Figure 3 shows the simulated RHCP (Right-Handed Circularly Polarized) patterns of the fabricated crossed dipole antenna without the four parasitic strips. As shown in Figure 3, it can be clearly seen that the patterns at lower frequencies have narrower beamwidths than those at the higher frequencies, i.e., the radiation patterns are non-uniform from 1.1 GHz to 1.6 GHz.

Figure 4 shows the simulated RHCP patterns of the fabricated crossed dipole antenna with the four parasitic strips. Here, it can be clearly seen that the patterns at lower frequencies are broadened, i.e., the radiation patterns become uniform from 1.1 GHz to 1.6 GHz.

In order to show quantitatively the discrepancy between the radiation patterns in Figure 3 and Figure 4, the values of the two patterns (corresponding to the patterns in Figure 3 and Figure 4) at a selected elevation angle $\theta = 70°$ against frequency are shown in Figure 5. Here, the curve A and curve B describe the pattern values against frequency for the crossed dipole antenna without and with the parasitic strips, respectively.

As can be seen in Figure 5, the pattern values of the crossed dipole antenna at $\theta = 70°$ are improved for the lower frequencies. The fluctuations of the pattern values at $\theta = 70°$ for the curve A and curve B are 6.38 dB and 1.5 dB across the frequency range 1.1 GHz to 1.6 GHz, respectively. The pattern values for the crossed dipole antenna at other elevation angles around $\theta = 70°$ are also investigated and show similar improvements, which indicates quantitatively that the patterns of the crossed dipole antenna are broadened and become more uniform across the frequency range 1.1 GHz to 1.6 GHz by introducing the four parasitic strips.

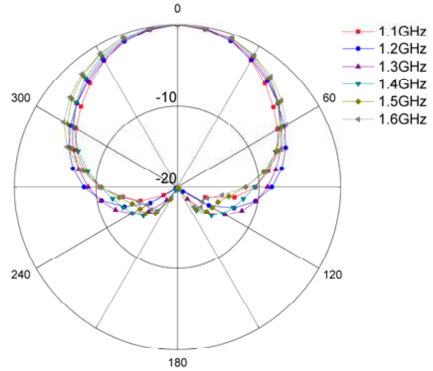

Figure 4. Simulated RHCP patterns of the fabricated crossed dipole antenna with parasitic strips.

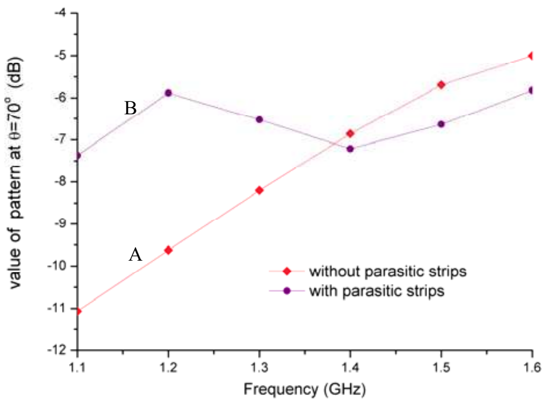

Figure 5. Comparison of the values of the two patterns shown in Figure 3 and Figure 4 against frequency when $\theta = 70°$.

The RHCP radiation patterns of the fabricated prototype, measured in an anechoic chamber at the frequencies of 1.1 GHz, 1.3 GHz and 1.6 GHz respectively, are shown in Figure 6, from which we can see that the patterns at lower frequencies are broadened, and the more uniform patterns over the wide frequency band are obtained. By comparing Figure 6 and Figure 4, we can see that the measured radiation patterns are agreement with the simulated radiation patterns.

To examine the effects of the parasitic strips on the return loss of the crossed dipole antenna, the VSWRs for the fabricated prototype were measured by using a vector network analyzer HP8753D under two situations: First, the VSWRs for one of the crossed dipoles, with and without the four parasitic strips, were measured to examine the effects of the parasitic strips directly on the return loss of the crossed dipole antenna, and the measured results are shown in Figure 7 as curve A' and curve A, respectively. By comparing the curve A' and curve A, it can be seen that the effect of the parasitic strips are mainly occurs in the frequency range about 1.2 GHz to 1.3 GHz, which may be due to the fact that the parasitic strip resonates in this frequency range. Note that the antenna still has a certain impedance mismatch and the VSWRs approach to 3.6 : 1 at lower frequencies. Second, the VSWRs for the crossed dipole antenna with the Lange coupler, with and without the four parasitic strips, were measured to examine the effects of the parasitic strips indirectly on the return loss of the whole

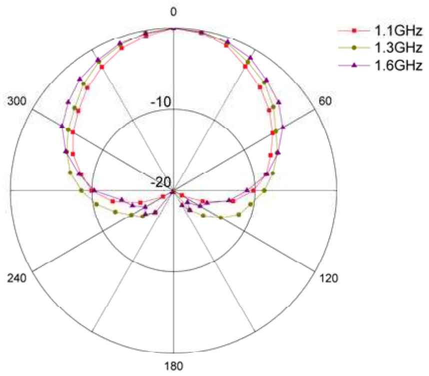

Figure 6. The RHCP radiation patterns measured at 1.1 GHz, 1.3 GHz and 1.6 GHz.

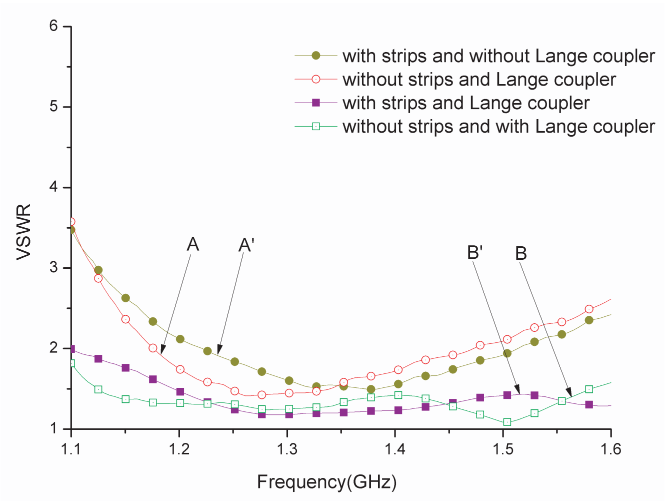

Figure 7. Measured VSWRs for the fabricated prototype.

antenna, and the measured results are shown in Figure 7 as curve B' and curve B, respectively. Under such a situation, the effects of the parasitic strips are small and the VSWRs are less than 2 : 1, which may be explained by the fact that the quadrature feeding configuration cancels the reflected signals at the input port of Lange coupler, hence improving the impedance matching performance.

4. CONCLUSION

In this paper, a method to broaden the beamwidths of a crossed dipole antenna is proposed. By introducing four parasitic strips around the crossed dipole antenna, the beamwidths of the crossed dipole antenna in the vertical plane are broadened effectively, making the patterns uniform over a wide frequency band. An L-band prototype, operating in the frequency range from 1.1 GHz to 1.6 GHz, is fabricated and tested. The simulated and measured results show that the beamwidths at lower frequencies are broadened and uniform radiation patterns over the whole operating frequency band are obtained. The antenna still has a certain impedance mismatch. Further study will be focused on improving the impedance matching performance. In a word, the method broadens the beamwidths effectively while leads to slight effects on the impedance matching performance, making it suitable for designing antennas for marine GPS applications. It's reasonable to assume that the method proposed in this paper can also be used to develop antennas for other potential applications.

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