Circularly Polarized Loop Antennas with a Parasitic Element for Bandwidth Enhancement

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Abstract: In this paper, it is demonstrated that the bandwidth of circular polarization (CP) for a loop antenna can be significantly increased when adding one more parasitic loop inside the original loop. The axial ratio (AR≤2 dB) bandwidth of the circular-loop antenna with a parasitic circular loop is found to be 20%, more than three times the AR bandwidth (about 6.5%) of a single loop. A bandwidth of 30% (AR≤2 dB) with a gain of more than 10 dBi is obtained for a series-fed dual rhombic-loop antenna while a bandwidth of 50% for AR ≤2 dB can be realized for the parallel-fed dual rhombic loop. This type of wideband CP antennas has two important features: i) easy to change the sense of CP; ii) able to implement an antenna array in a coplanar stripline circuit.

I. INTRODUCTION

Loop antennas (such as circular, square, triangular, rectangular, and rhombic loops) are usually used as linearly polarized antennas [1]. In recent years, it has been found that a loop antenna can also radiate circularly polarized (CP) waves if a gap is introduced on the loop [2]-[5]. The reason for the CP radiation is the traveling-wave current distribution that gets excited along the loop. Compared to conventional center-fed planar spiral antennas [6], the CP loop antennas have two important advantages. First the loop antenna is fed on its perimeter, making it possible to directly integrate an antenna array in a coplanar stripline circuit [7]. Second the sense of circular polarization can be easily switched from left-hand to right-hand, and vice versa, by altering the gap positions using radio-frequency (RF) switches such as microelectro-mechanical systems (MEMS), optoelectronic switches, or PIN diodes. Unfortunately the bandwidth of the CP loop antennas is much less than that achieved by spiral antennas [8]. In this paper, it will be demonstrated that the AR bandwidth of a CP loop antenna can be significantly increased by adding a similar loop inside the original loop. The addition of a parasitic element can produce two minimum AR points that lead to a considerable enhancement for the AR bandwidth. Since the additional parasitic element is placed inside the original loop and there is no direct electrical connection to its surrounding, there is no significant increase in the size and complexity of the antenna structure. It will be shown that for a circular-loop antenna the AR (≤2 dB) bandwidth be can be increased from 6.5% to 20% by the addition of a parasitic circular loop. A bandwidth of 30% with a gain of more than 10 dBi can be obtained for a series-fed dual rhombic-loop antenna while a parallel-fed dual rhombic-loop antenna with a parasitic element can achieve a bandwidth of 50% for AR ≤2 dB.

II. A CIRCULAR-LOOP ANTENNA WITH A PARASITIC ELEMENT

As shown in Fig. 1, the antenna consists of two concentric coplanar wire loops (Loop 1 and Loop 2) placed above a ground plane at a height *h*. Loop 1 (the larger one), fed at $\phi=0$ by a voltage source V_0, acts as a primary element while Loop 2 (the smaller one) serves as a parasitic element. In order to radiate a CP wave, a small gap is introduced on each loop. The size (or the radius R_1) of Loop 1 is determined by the lower limit of an operating frequency band (its circumference is slightly longer than one wavelength at the lower frequency). By adjusting the size (or the radius R_2) of Loop 2, the positions (at $\phi=\phi_1$ for Gap 1 and $\phi=\phi_2$ for Gap 2) of gaps, and the height *h*, an optimal performance for the on-axis (in the z direction) axial ratio can be achieved.

The circular-loop antenna with a parasitic element is numerically simulated using NEC 1.1. Both of the gap widths ($\Delta\phi_1$ for Gap 1 and $\Delta\phi_2$ for Gap 2) are 5 degrees. The wire radius (r_1) of Loop 1 is two times the radius (r_2) of Loop 2, which is set at $r_2=0.0058\lambda_0$, where λ_0 is the free-space wavelength at the center frequency f_c. The circumference of Loop 1 is found to be $1.288\lambda_0$ while the circumference of Loop 2 and the height *h* are optimized to be $0.867\lambda_0$ and $0.236\lambda_0$, respectively. The optimal gap positions are found to be at $\phi_1=55°$, $\phi_2=65°$. Note that the position of Gap 1 needs to be moved to $\phi_1=40°$ if without the parasitic element (i.e. Loop 2).

Fig. 2 shows the axial ratio comparison between the circular-loop antennas with and without the parasitic element. It can be seen that the AR (≤2 dB) bandwidth is increased from 6.5% to 20% by introducing the parasitic element. It is also observed that there are two minimum AR points appearing at a lower (than the center frequency f_c) frequency f_L and at a higher frequency f_H, respectively. It is the combination of the two minimum AR points that results in the bandwidth enhancement. The AR bandwidth can be further increased at the expense of a higher maximum AR criterion (AR_{max}).

III. DUAL RHOMBIC-LOOP ANTENNAS WITH A PARASITIC ELEMENT

The dual rhombic-loop antenna which consists of two rhombic loops is developed in [3] with two types of feed configurations: (i) series feed and (ii) parallel feed. An AR bandwidth of more than 20% (AR≤2 dB) has been obtained for a parallel-fed dual rhombic-loop antenna [3]. In this section, it will be demonstrated that an AR bandwidth of 50% for AR≤2 dB can be achieved for the parallel-fed dual rhombic-loop antenna by adding a parasitic element. Fig. 3 depicts the geometry of a dual rhombic-loop antenna with i) a series feed and ii) a parallel feed. A similar rhombic loop (Loop 2) is placed inside of each of the two primary rhombic loops (Loop 1). There is a small gap ($<0.025\lambda_0$) along each of the loops. The optimal AR of the dual rhombic-loop antenna can be obtained by adjusting the size of the parasitic element, the positions of the gaps, and the height of the loops above the ground plane.

Fig. 4 shows the AR comparison between the series-fed dual rhombic-loop antennas with and without a parasitic element. We can see that the bandwidth for AR≤2 dB is increased from 12 % to 30% by adding the parasitic element. For the parallel feed, the AR is compared in Fig. 5 between the dual rhombic-loop antennas with and without the parasitic element. It is observed that the AR≤2 dB bandwidth is increased from 25% to 50% by introducing the parasitic element. More importantly, a very low maximum AR (<0.75 dB) is obtained and it is seen that the AR bandwidth for AR ≤1 dB is near 40%.

To confirm the bandwidth enhancement by the parasitic element, a series-fed dual rhombic-loop antenna is fabricated and measured. Fig. 6 presents the simulated and measured results for the axial ratio and gain, showing good agreement. The AR bandwidth for AR<2 dB is found to be about 30% and the gain is higher than 10 dBi. Fig. 7 shows the frequency characteristics of input impedance of the series-fed dual rhombic-loop antenna, also indicating a wideband performance.

IV. CONCLUSION

It has been demonstrated that the bandwidth for circular polarization of a loop antenna can be significantly increased by incorporating a similar loop inside the original loop. It has been found that the AR (≤ 2 dB) bandwidth of the circular-loop antenna with a parasitic circular loop can be increased from 6.5% (without the parasitic element) to 20%. A bandwidth of 30% (AR≤ 2 dB) with a gain of more than 10 dBi has been obtained for a series-fed dual rhombic-loop antenna with a parasitic dual rhombic loop while a bandwidth of 50% for AR ≤2 dB can be realized for the parallel-fed dual rhombic loop by adding a parasitic element. An experimental example confirms the bandwidth enhancement.

Acknowledgement

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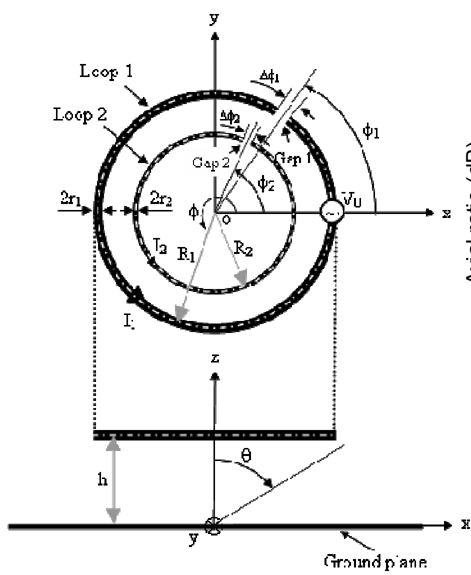

Fig. 1. Geometry of a CP circular-loop antenna with a parasitic circular loop for bandwidth enhancement.

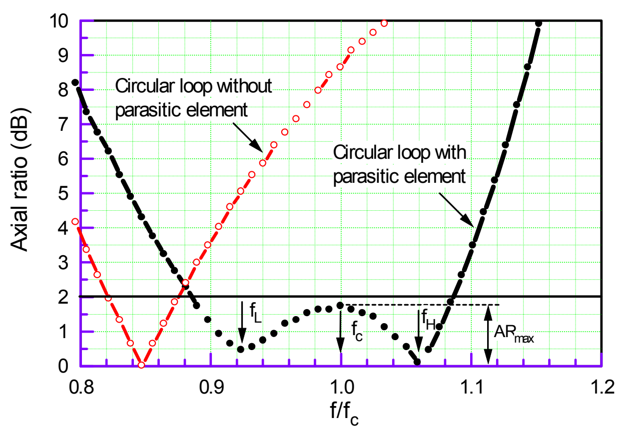

Fig. 2. Axial ratio comparison between the circular-loop antennas with and without a parasitic element [geometric parameters: R_1=0.205λ_0, R_2=0.138λ_0, h=0.236λ_0, r_1=0.0118λ_0, r_2=0.0059λ_0, ϕ_1=55° (ϕ_1=40° if without the parasitic element), ϕ_2=65°, $\Delta\phi_1$=5°, and $\Delta\phi_2$=5°].

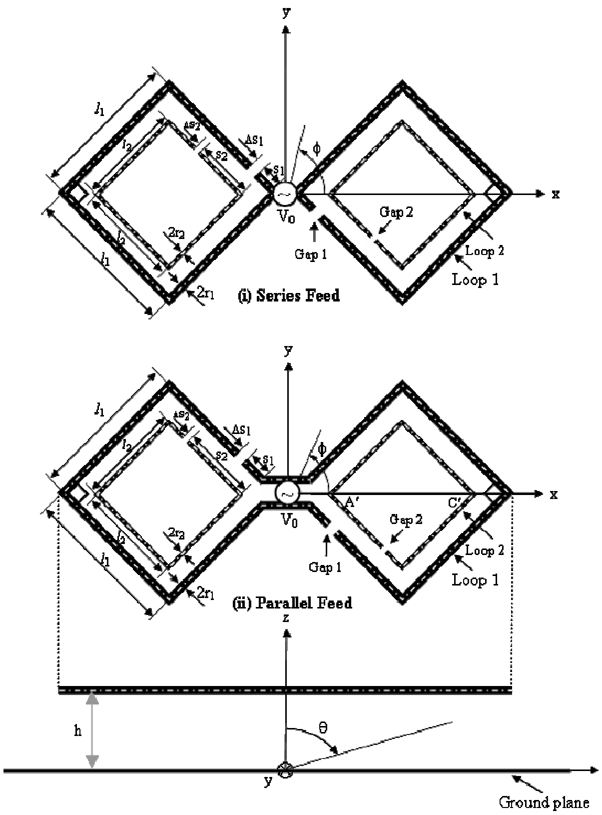

Fig. 3. Geometry of series- and parallel-fed dual rhombic-loop antennas with a parasitic dual rhombic loop.

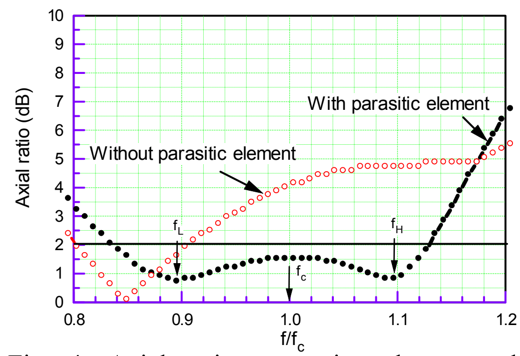

Fig. 4. Axial ratio comparison between the series-fed dual rhombic-loop antennas with and without a parasitic element (geometric parameters: $l_1=0.345\lambda_0$, $l_2=0.216\lambda_0$, $s_1=0$, $s_2=0.158\lambda_0$, $\Delta s_1=0.023\lambda_0$, $\Delta s_2=0.0105\lambda_0$, $r_1=0.0086\lambda_0$, $r_2=0.0043\lambda_0$, $h=0.28\lambda_0$, and $\beta=90°$).

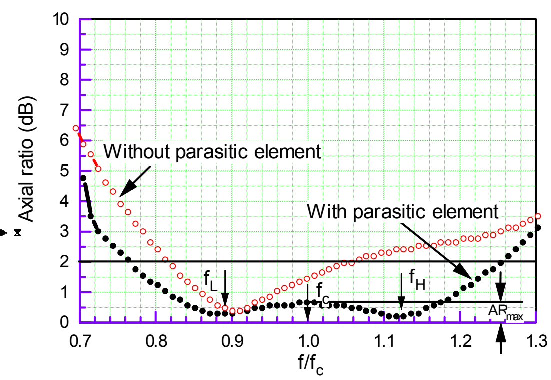

Fig. 5. Axial ratio comparison between the parallel-fed dual rhombic-loop antennas with and without a parasitic element [geometric parameters: $l_1=0.272\lambda_0$, $l_2=0.17\lambda_0$, $s_1=0.072\lambda_0$ ($s_1=0.018\lambda_0$ if without the parasitic element), $s_2=0.125\lambda_0$, $\Delta s_1=0.018\lambda_0$, $\Delta s_2=0.011\lambda_0$, $r_1=0.01\lambda_0$, $r_2=0.005\lambda_0$, $h=0.323\lambda_0$, and $\beta=90°$].

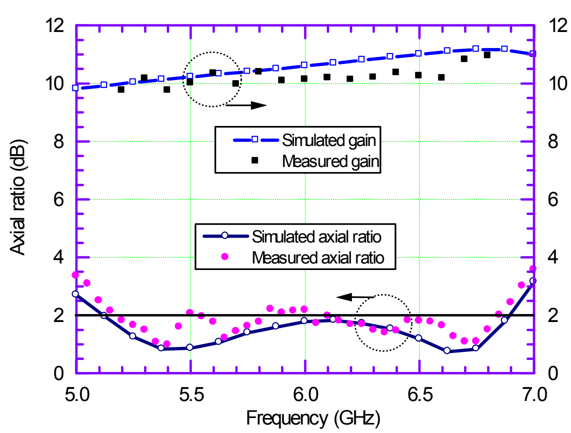

Fig. 6. Comparison of simulated and measured results for axial ratio and gain of the series-fed dual rhombic-loop antenna with a parasitic element.

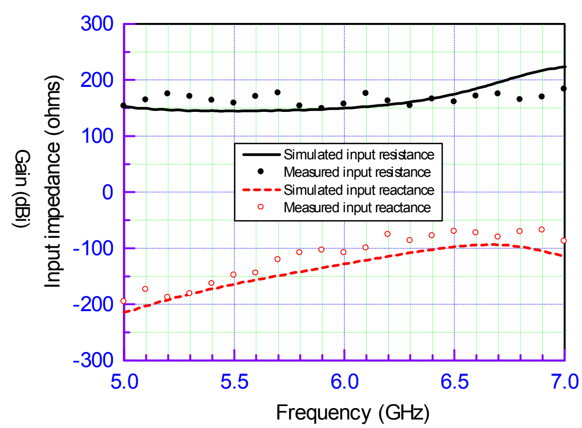

Fig. 7. Comparison of simulated and measured results for input impedance of the series-fed dual rhombic-loop antenna with a parasitic element.