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Circularly polarized rectangular dielectric resonator antennas with branch-line coupler for wideband applications

Z. Rahimian*, S. Nikmehr, A. pourziad

Department of Electrical & Computer Engineering, University of Tabriz, Tabriz 5155974851, Iran

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ABSTRACT

In this paper, two circularly polarized rectangular dielectric resonator antennas (RDRAs) are proposed for wideband applications. One common method for achieving the orthogonal modes for circular polarization is used by coupler. In this configuration, a 45° rotated branch-line coupler which is located under the hollow RDRA with two tapered excitation strips are connected to sidewall of RDRA to excite two degenerate TE_{111} modes is used. For the second antenna, a pair of tapered stubs and metallic vias is added to structure to increase bandwidth, and antenna gain. These antennas exhibit better results in comparison with similar conventional DRA with similar feeding technique. The major differences of the proposed antenna compared to the prior arts were using a few simple techniques simultaneously to improve impedance and axial ratio (AR) bandwidths, gain, and cost of structure. These techniques consist of using wideband branch-line coupler, hollow RDRA, placing the coupler under DR with 45° rotation, tapered excitation strip, FR4 substrate, and tapered stubs and metal vias in the second antenna. Both simulated and measured results are presented. These first and the second antennas offer an impedance bandwidth ($S_{11} < -10$ dB) of 69.4% and 96.3%, and axial ratio bandwidth (AR < 3 dB) of 52.45% and 57%, respectively.

1. Introduction

The discovery of dielectric resonator antennas (DRAs) dates back to 1983 by Long et al. [1]. During the past two decades, DRA has been widely explored. These antennas have several advantages such as small size, light weight, ease of excitation and the ability to obtain different radiation patterns by the proper excitation of various resonant modes [1–9]. More importantly, the inherent disadvantages of conventional metallic antennas such as high conduction loss at millimeter wave frequencies, and low efficiency are avoided by DRA [3]. Dielectric resonators of different shapes have various modes of resonances. With the proper excitation of certain modes, these resonators can actually become efficient radiators instead of energy storage devices [4]. The shape of DRA can be hemispherical, cylindrical or rectangular. Among these shapes, the rectangular one has the largest number of design parameters (width, length, and height) and hence is the most appropriate one for design purposes [2,5]. By selecting proper dimensions of the rectangular DRA (RDRA), the mode degeneracy problem can be avoided and, in addition, the bandwidth can be optimized [9]. Primary conducted studies on DRA have been mainly focused on the linear polarization applications, bandwidth enhancing techniques such as excitation of higher order modes, combination of hybrid modes and array applications [10–13]. Nevertheless, designing a wideband circularly polarized (CP) DRA is still a challenging task. It is difficult to simultaneously obtain wide impedance and axial ratio (AR) bandwidths. Circularly polarized (CP) DRA has received tremendous attention [14–20], mainly due to its ability to reduce the polarization mismatch.

Several techniques have been proposed to generate CP using DRAs. These techniques can be classified into three categories: (1) using a single port, (2) using a single port to excite two modes, and (3) using multiple ports to excite two modes. The first method makes use of a single port and change in the geometry conditions of DR to excite degenerate modes, for the generation of CP fields. For example specially shaped DRAs have been investigated in [14,15]. These designs make use of slots on the side walls of DRAs to excite degenerate modes, for generation of CP fields with 3 dB AR bandwidth of 8.2%. The second method applies a single port and ordinary DR to excite two modes which are geometrically orthogonal and quasi-degenerate. The quasi-degeneracy of the modes provides the phase quadrature between the modes. For example the bowtie cross-slot coupled cylindrical DRA with 3 dB AR bandwidth of 17.24% has been reported in [16]. The rectangular DRA with a square spiral microstrip feedline with 3 dB AR bandwidth of 15.5% has been reported in [17]. A CP quadruple strip fed cylindrical DRA

* Corresponding author.
E-mail address: z_rahimian89@ms.tabrizu.ac.ir (Z. Rahimian).

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utilizing a pair of 90° hybrid couplers and providing an axial ratio bandwidth of 25.9% has been investigated in [18]. Ref. [19] describes design of a dual wide-band cylindrical DRAs to obtain CP fields with the quadrature strip-fed method. They reported a measured 3 dB AR bandwidth of 24.7%. The third method employs multiple ports in order to excite two modes which are geometrically orthogonal. The multiple feeds are used to create the phase quadrature between the modes. For example a RDRA fed by two vertical strips which are quadrature in phase was studied in [20]. In Ref. [21] a cylindrical DRA fed by four sequentially rotated slots was investigated and good AR bandwidth for covering satellite navigation systems was obtained.

In this paper the main differences of the proposed antenna compared to the previous paper were using a few simple techniques simultaneously to improve results of antenna. These techniques expression are follow: (1) Using wideband coupler such as branch-line coupler instead of other coupler, the result of this choice is orthogonal modes excite stronger. Extensive simulation results about different coupler as a feeding network shows that axial ratio bandwidth increase when branch-line coupler is used. Also we claimed axial ratio bandwidth is a direct relationship to excitation orthogonal modes, because the coupler can excite two orthogonal modes to generate better CP fields and obtain wide axial ratio bandwidth. (2) Using hollow RDRA, the result of this choice is the hollow DRA has a smaller Q factor than its solid counterpart, it will provide a larger antenna bandwidth. (3) Placing the coupler under DR with 45° rotation instead of horizontal or vertical situation, this insertion is the best choice because of no extra space is needed for the coupler, making the system very compact. Also with this compact configuration, loss of the feed network and, hence, reduction in the antenna gain, can be minimized. (4) Using tapered excitation strip instead of rectangular strip to provide better impedance matching and increase AR bandwidth. (5) Using FR4 substrate, the result of this choice is obtaining a low cost structure. (6) Using two tapered microstrip stubs of length $\lambda g/4$ and metal vias in the second antenna, tapered stub acts as an open circuit and returns some of the electric field back to the vertical strip and thus stronger operating modes are excited. With this approach, a wide impedance and AR bandwidth and high gain can be obtained. This paper investigates the first and second antennas geometry and design in Section 2. These antennas have been simulated using the Ansoft HFSS 13, and fabricated. Section 3 describes the results from simulations and measurements of the parameters of the two antennas including the −10 dB reflection coefficient bandwidth, 3 dB AR bandwidth, antenna gain, radiation pattern, electrical field distributions, and radiation efficiency. In addition, an extensive parametric study is done for a range of variations of some geometrical dimensions of the first design. Finally, concluding remarks are presented in Section 4.

2. Antennas geometry and design

The CP hollow RDRAs design using 45° rotated wideband branch-line coupler is given in this section. Fig. 1(a) and (b) shows the configuration of the first hollow RDRA. In addition, Fig. 2 shows the second antenna, which is designed by two tapered microstrip stubs and metal vias. In this paper, the dielectric waveguide model (DWM) has been used to determine the resonance frequency of the hollow rectangular dielectric resonator antenna (RDRA) [22].

2.1. The first antenna geometry and design

The first hollow RDRA was designed to resonate at around 9 GHz, in X-band frequency. The hollow RDRA has a dielectric constant of $\varepsilon_r = 10$ and a square cross section with dimensions of $a_1 = 18$ mm, $d_1 = 2.5$ mm, $a_2 = 11.6$ mm, and $d_2 = 0.8$ mm. Having removed the central portion of DR, the effective dielectric constant and the radiation quality factor of the RDRA are decreased and, therefore, the impedance bandwidth is increased [23]. We apply a 45° rotated

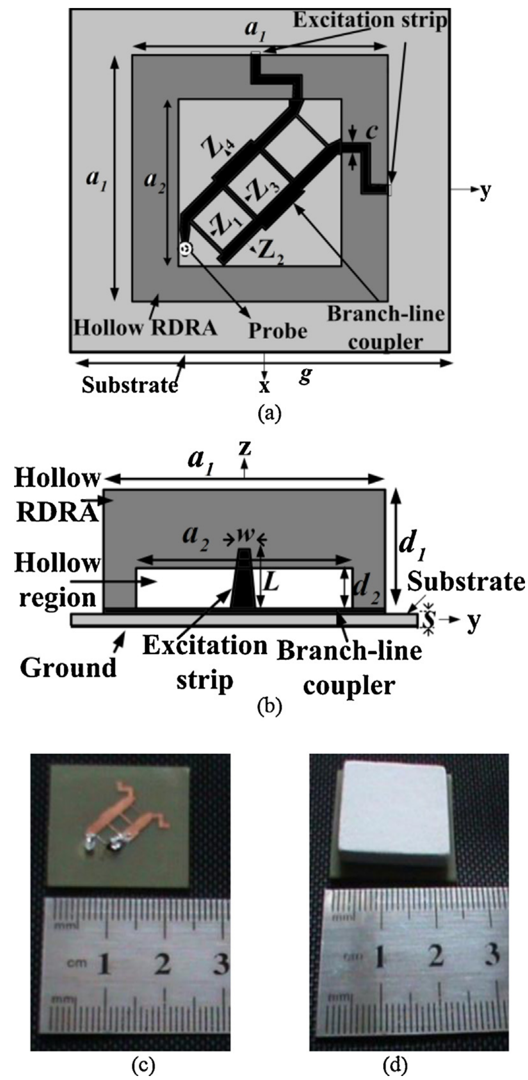

Fig. 1. Configuration of the first antenna: (a) Top view, (b) cross sectional view, (c) photograph of the fabricated branch-line coupler, (d) photograph of the fabricated antenna $\varepsilon_r = 10$, $a_1 = 18$ mm, $d_1 = 2.5$ mm, $a_2 = 11.6$ mm, and $d_2 = 0.8$ mm, $c = 0.8$ mm, and $S = 0.8$ mm.

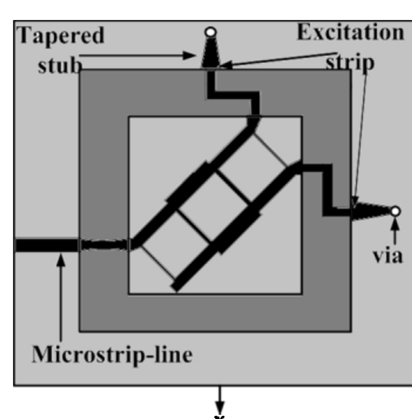

Fig. 2. Configuration of the second antenna (top view).