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Design of a wideband high gain antenna using FSS for circularly polarized applications

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ABSTRACT

This paper presents a high gain, wideband circularly polarized (CP) antenna. High gain of the antenna is achieved by employing an FSS as a reflector. The antenna is a coplanar waveguide (CPW) fed structure with a modified L-shaped radiating patch. The unit element of the FSS is formed by connecting two modified dipoles at an angle 90°. The FSS array is made from unit elements of varying size such that the bigger size elements are at the center while smaller are at the edges. After application of the reflector, the antenna and FSS dimensions are further optimized to get maximum impedance bandwidth and axial ratio bandwidth (ARBW) simultaneously. Also the FSS array is made defected by etching out two elements of the array to maintain the ARBW. The antenna with reflector has a measured impedance bandwidth of 74.3% (2.2–4.8 GHz) and a 3-dB ARBW of 62% (2.2–4.18 GHz). The measured boresight gain of the proposed antenna is increased by around 3–4 dB after applying FSS in the CP operation band. The radiation patterns of the antenna with the FSS are also measured and compared with simulated patterns. The various aspects of effect of FSS on CP antenna performance are also discussed.

1. Introduction

Recently, printed antenna technology gained much of the attention from the antenna designers due to its low profile and ease of fabrication features. Among these, CP antennas are very popular due to their merit over linearly polarized (LP) antennas in terms of Faraday rotation insensitivity, weather penetration and no requirement of the strict orientation of receiver and transmitter [1]. High data transfer rate requires a broad bandwidth whereas the ease of handling requires compact antennas. CPW-fed slot antennas fit into the aforementioned category because as they are compact, low profile and broadband in nature. But the printed antennas suffer from a inherit disadvantage of low gain. Therefore, low profile, high gain printed wideband antenna with CP radiations is required to achieve the best performance in a wireless device.

In the recent past, many efforts have been made to achieve high gain for printed CP antennas. High gain CP antennas can be obtained either by increasing the gain of a CP antenna with the help of reflectors and superstrates [2–5] or by using a polarizer to convert LP radiations from an antenna to CP radiations [6–9]. High gain of the printed CP antenna can also be achieved by using array structure, but it requires a complex feeding network [10,11]. Recently metamaterial structures are also utilized to enhance the performance of LP [12,13] and CP antennas [14–16]. In [2], the gain of a CP antenna is increased by using FSS as a reflector. The impedance bandwidth and the ARBW are 36.67% and 23.33% respectively. The gain of a CPW-fed slot antenna in [3] is enhanced by a dipole type FSS used as a reflector. The achieved ARBW is 40%. In [4], high gain of a CP antenna is achieved by using a ring shaped FSS as a superstrate layer. The operating bandwidth of the antenna with the FSS is 2.4%. In [5], the gain of a CP antenna is enhanced by using a slot type FSS as a superstrate layer. The operating BW is 4.73%. In [14], a novel concept to design compact CP antenna is proposed by using fractal metasurface and fractal resonator. The CP radiation is achieved by complementary split ring resonator. This antenna has a compact size of $40 \times 45 \times 2.5$ mm^3. The operating band of this antenna is 1.86%. In [15], a Chiral metamaterial is utilized to convert LP incident waves to CP waves for dual band in X-band. The LP to CP conversion achieved due to twisted split ring resonators. A reduced size single feed CP patch antenna with metasurface and metal resonators is presented in [16]. The achieved ARBW is 1.05% at 3 GHz. The most of the above designed antennas have narrow CP operation bandwidth.

In this paper, a high gain, CP antenna for broadband operation is designed. The antenna is a CPW-fed slot structure excited by an L-shaped patch. An FSS is used to enhance the gain of the antenna

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whose unit element has two center connected modified dipoles. The FSS array is made by varying size unit elements and also made defected by removing two elements. This gives an additional degree of freedom which helps in maintaining the ARBW. The achieved impedance bandwidth and ARBW with the FSS are 74.3% and 62% respectively. To the best of the author's knowledge, no paper has been reported in the open literature to enhance the gain of a CP antenna with such a huge operating bandwidth. The proposed high gain CP antenna can have applications in WLAN, WiMax and satellite systems.

2. Antenna description

The antenna geometry is shown in Fig. 1. The antenna is designed on a FR-4 substrate of dielectric constant 4.4 and thickness of 1.6 mm. A rectangular slot is etched out from the ground plane. This slot is excited by an L-shaped patch with a 50 ohm CPW-fed line. The patch is selected as L-shaped to generate two orthogonal modes with 90° phase difference. With this structure a very narrow ARBW is achieved. To increase the ARBW, the surface current distributions and electric field distributions are studied on either side of the achieved CP operation frequency. It is found that, there is a larger difference between the amplitudes of the both the orthogonal modes. To equate these orthogonal modes, two additional rectangular slots are etched out from the ground plane. The lengths of the slots are chosen as $\lambda/4$ at the selected frequencies. The slots are placed horizontally to generate extra vertical fields which are required to equate the magnitude of both the modes. Further to achieve the CP at the lower frequencies the larger arm of the L-shaped patch is connected with the ground plane with an additional rectangular patch via a slit. This serves two purposes, first it equates the amplitude of the two orthogonal modes and second, it generates a phase difference of 90° between the two orthogonal modes. After that, the operating band frequencies are identified at which AR is greater than 3 dB. Two additional slots are etched in the ground plane to bring the AR less than 3 dB at earlier identified frequencies. The position and the length of these slots are selected according to the current distribution and electric field distribution at the identified frequencies. The detail of the antenna design can be found in [17]. Finally, the dimensions of the antenna are optimized for maximum impedance bandwidth and ARBW simultaneously. The optimized dimensions of the antenna are given in Table 1.

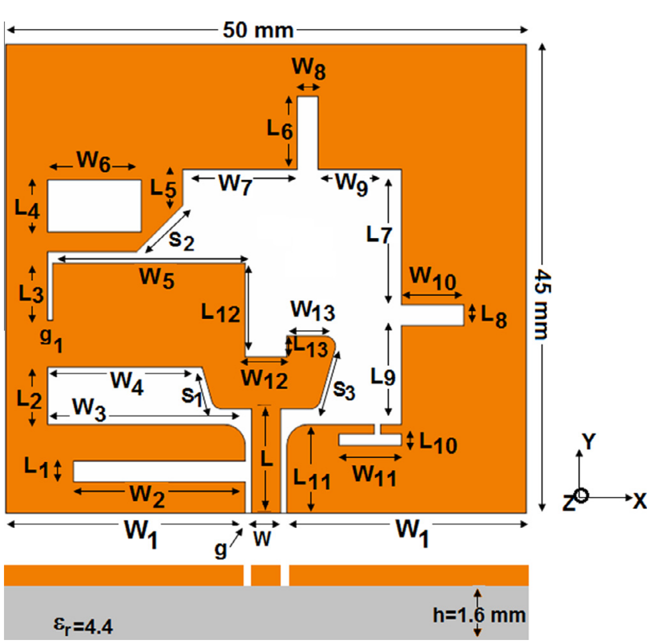

Fig. 1. Geometry of the circularly polarized antenna.

Table 1
Optimized dimensions of the antenna in mm.

Parameter	W_1	W_2	W_3	W_4	W_5	W_6	W_7
Value	23	16.7	19	14.5	18.5	9	11
Parameter	W_8	W_9	W_{10}	W_{11}	W_{12}	W_{13}	L_1
Value	2	8	6	6	4	4	2
Parameter	L_2	L_3	L_4	L_5	L_6	L_7	L_8
Value	5.5	5.5	5	3.5	7	13	2
Parameter	L_9	L_{10}	L_{11}	L_{12}	L_{13}	S_1	S_2
Value	9.5	1.1	8.5	9	2	4.5	6.3
Parameter	S_3	L	W	g	g_1	g_2	g_3
Value	5.2	10	2.8	0.6	0.5	0.6	0.8

3. FSS unit element and array design

The geometry of the unit element of the FSS is shown in Fig. 2 (a). The FSS is designed on FR-4 substrate of thickness 1.6 mm and dielectric constant 4.4 mm. The unit element is designed using two modified symmetric dipoles connected with the center at an angle 90°. The unit element structure is chosen such that it can reflect the two orthogonal waves with nearly same characteristics. The dipoles are of steps structure such that the center of the dipole is narrower while both the sides of the dipole are wider. The step design is chosen to increase the electrical length of the FSS element. The dimension of a unit element is selected as 23 mm × 23 mm. The total length of the dipole is $2L$. The length of the narrow section is $2nL$ while the wider section is $2L(1-n)$ mm long. The width of the narrow section is pL while that of wider section is mL. The length and width of the sections are selected in terms of total length of the dipole so that by only changing the length, the structure is easily optimized.

The FSS array is designed using variable size unit elements. The size of the elements is varied successively such that the elements located at the center of the array have larger size while the elements at outer has smallest size. The sizes of the patches are chosen in the aforementioned manner to compensate the phase mismatch due to difference in the path length for the center elements and the elements at the edge of the FSS array. As the path length between antenna and the center of the array is smaller as comparison to the path length between antenna and elements at the edge of the array. Therefore, to compensate the phase difference due to difference in path length the center elements are chosen bigger while elements at the edges are smaller. The FSS array is shown in Fig. 3(b). As discussed earlier, the dimensions of the modified dipole depend on its length. Therefore, the length of the dipole is varied and the other dimensions are automatically changed according to the value of m, n and p. The initial dimensions of the unit element are selected such that the maximum reflection frequency of the FSS coincides with the center frequency of the CP operation. For the proposed unit element the equivalent circuit is shown in Fig. 3. The inductance L_{FSS} is due to the narrow section of the FSS and the capacitance C_{FSS} is due to the coupling of electric fields between the two unit elements. The L_{FSS} and C_{FSS} can be calculated by [18]:

$$L_{FSS} = \frac{Z_0}{c} 2nL \tag{1}$$

$$C_{FSS} = \frac{2mL}{\pi} \varepsilon_0 \varepsilon_{eff} \cosh^{-1}\left(\frac{4L(1-n)}{g_{FSS}}\right) \tag{2}$$