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Design of ultra wideband trapezoidal shape slot antenna with circular polarization

R.V.S. Ram Krishna [a,b], Raj Kumar [a,b,*]

[a] DIAT (Deemed University), Girinagar, Pune 411 025, India
[b] ARDE, Pashan, Pune 411 041, India

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ABSTRACT

A CPW-feed printed slot antenna with circular polarization characteristics is presented in this paper. The basic structure of the antenna is a rectangular slot excited by a 50 Ω CPW line terminated on a trapezoidal shaped tuning stub. Perturbations in the form of circular stubs are applied in the slot to realize circular polarization. The measured impedance bandwidth ($S_{11} < -10$ dB) for the initial design is 4.4 GHz (from 2.2 GHz to 6.6 GHz) while the 3-dB axial ratio bandwidth is 1.77 GHz (from 4 GHz to 5.77 GHz) which is 36.23% at the center frequency of 4.88 GHz. The basic structure of the antenna was further modified to enhance the impedance bandwidth to reach well beyond 12 GHz while increasing the ARBW to 44.3% (from 4.3 GHz to 6.75 GHz). The proposed antenna in its final version has a measured peak gain of about 5 dB throughout the useful band and nearly stable radiation pattern.

1. Introduction

Circular polarization (CP) has become accepted as one of the very desirable characteristics of an ultra wideband antenna. However, circular polarization, which is the limiting case of the more general elliptical polarization is rather difficult to achieve due to the stringent demands on the phase and is realized only in the presence of two orthogonal components of the electric field vector in exact phase quadrature. Traditionally, circularly polarized antennas were used for point to point satellite communications and as such, the antennas used to realize CP had no space constraints and could afford to be bulky. Crossed dipoles, Archimedean Spirals and Yagi Udas provided the required circular polarization characteristics. The rapid growth in wireless communications coupled with the widespread use of the hand held mobile and other portable devices led to a flurry of research in the field of microstrip antennas. Moreover, the release of spectrum by the Federal Communications Commission (FCC) for Personal Area Network (PAN) operations has placed an increasing demand on the versatility of the basic microstrip patch antenna requiring it to be compact in size, robust in design and nearly omnidirectional in radiation while at the same time offering a large impedance bandwidth to be suitable for several applications in the ultra wideband region.

Interest in the circular polarization characteristic of the microstrip antenna grew primarily due to its ability to combat multipath fading and thus support higher data rates and also allowing for a flexible receiver orientation. Accordingly, the patch antenna in all its varieties is being studied for ideal circular polarization characteristics. Among the various structures being investigated, the CPW fed slot antenna can be considered as the ideal candidate since it has less radiation loss, offers good radiation patterns and can be easily integrated with monolithic microwave integrated circuits (MMIC).

A number of slot antenna designs for CP have appeared in the published literature. In [1], a halberd shaped tuning stub was used to excite a square slot and a CP band of 1575 MHz (3.81%) was achieved. A stair shaped slot antenna was proposed in [2] that gave a 31.2% axial ratio (AR) bandwidth from 2.30 to 3.15 GHz. A square slot antenna with lightening-shaped feedline and inverted-L grounded strips was presented in [3] which gave a useful bandwidth of 48%. Axial ratio enhancement using asymmetric CPW line was discussed in [4] while a hexagonal slot antenna fed by a L-shaped monopole was proposed in [5] which gave an ARBW of about 50%. A tabulated comparison of some of the other slot antennas designed for circular polarization and proposed in the recent past is given in Table 1.

In this paper, the investigations on a 60 mm × 50 mm, rectangular slot antenna for improved impedance bandwidth with wide circular polarization characteristics are discussed. The slot is fed by a 50 Ω CPW line terminated on a trapezoidal shaped tuning stub. The regular shape of the slot is modified at the corners to enhance the useful band of operation. Three different prototypes are made. Modifications to the initial design are incorporated in subsequent designs. The performance of the prototypes as obtained by simulations on Ansoft HFSS and CST Microwave

* Corresponding author. Tel.: +91 2024304149.
E-mail addresses: rk_nedes@yahoo.co.in (R.V.S.R. Krishna), raj34_shivani@yahoo.co.in (R. Kumar).

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Table 1
Comparison of CP slot antennas proposed in the recent past.

Ref no,	Authors	Year	Size of the CP slot antenna	Axial ratio bandwidth	Impedance bandwidth
[3]	Sze et al.	2010	60 × 60	2.02–3.42 GHz (51%)	2.07–3.41 GHz (49%)
[4]	Sze et al.	2008	60 × 60	1.88–2.56 GHz (30.6%)	1.77–2.59 GHz
[5]	Zhou et al.	2011	62 × 62	2.25–3.75 GHz (50%)	1.80–4.50 GHz (86%)
[6]	Wang et al.	2012	60 × 50	2.26–2.47 GHz (8.9%)	1.69–2.78 GHz (49%)
[7]	Pourahmadazar et al.	2011	60 × 60	2.67–13.0 GHz (132%)	4.90–6.90 GHz (32%)
[8]	Chen et al.	2011	70 × 70	1.45–1.72 GHz (17%) and 1.86–2.29 GHz (21%)	1.47–1.61 GHz (9%) and 1.87 to 2.09 GHz (11%)
[9]	Chen et al.	2012	60 × 60	2.9–5.5 GHz (62%)	2.9–20 GHz (149%)
[10]	Chen et al.	2006	100 × 100	2.2–2.6 GHz (17%)	2.1–3.2 GHz (43%)
[11]	Pourahmadazar et al.	2011	25 × 25	5.01–7.38 GHz (38.2%)	2.98–11.23 GHz (118%)
[12]	Zaker et al.	2011	50 × 50	3.35–4.05 GHz (18.9%) 4.55–6.32 GHz (32.5%)	3.35–4.25 GHz (21%) 4.65–6.35 GHz (33%)
[13]	Sze et al.	2011	45 × 45	2.1–3.74 GHz	2.03–4.69 GHz
[14]	Nasimuddin et al.	2011	60 × 60	2.4–4.85 GHz (68%)	1.6–5.25 GHz (107%)
[15]	Nasimuddin et al.	2012	60 × 60	2.75–4.6 GHz (50%)	2.0–5.0 GHz (100%)
[16]	Jeevanandham et al.	2012	62 × 60	3.2–3.75 GHz (15.7%) 4.42–5.1 GHz (15.7%)	3.41–3.7 GHz (8.6%) 4.47–5.2 GHz (15.5%)
[17]	Li et al.	2013	54 × 54	2.85–5.21 GHz (58%)	1.78–5.64 GHz (104%)
[18]	Wang et al.	2012	60 × 60	2.7–6.4 GHz (82%)	1.9–6 GHz (91%)
[19]	Jan et al.	2013	50 × 50	1 GHz (27% at 3.7 GHz)	111% at 4.8 GHz
[20]	Felegari et al.	2011	60 × 60	2–5 GHz (85%)	2–7 GHz (110%)

Studio and verified by experimental results is discussed in subsequent sections.

2. Initial design of the antenna

2.1. Geometry

The initial design of the proposed antenna is shown in Fig. 1. As seen from the figure, a ground plane having dimensions $W_g \times L_g$ is printed on a commercially cheap FR4 substrate having relative permittivity $\varepsilon_r = 4.4$ and loss tangent tan $\delta = 0.0019$. The thickness of the substrate is $h = 1.53$ mm. A rectangular slot of dimensions $W \times L$ is etched on the ground plane and is excited by a 50 Ω CPW – feed line. The feed line is terminated on a trapezoidal shaped tuning stub protruding into the center of the slot. The stub enhances the coupling between the feedline and the slot. The rectangular slot is truncated by two circular shaped arcs at the lower left corner and the upper right corner. The arcs are of unequal radii and serve as perturbations necessary to realize CP. The spacing between the stub and the ground plane denoted by '*S*' and the gap between the feedline and the ground plane denoted by '*G*' are two parameters responsible for proper impedance matching and hence can be optimized. The trapezoidal shape stub has widths W_{s1} and W_{s2} and length L_s. The various parameter values are listed in Table 2.

Table 2
Dimensions of Antenna – 1.

S.no.	Parameter	Dimensions (in mm)
1	W_g	60
2	L_g	50
3	W	40
4	L	23
5	R_1	6
6	R_2	10
7	L_f	16.62
8	W_f	2.8
9	S	3.68
10	G	0.85
11	W_{s1}	7
12	W_{s2}	14
13	L_s	7.5
14	h	1.53

2.2. Measured and simulated reflection coefficient

The initial design (Antenna – 1) was simulated on two different electromagnetic software; one based on the Finite Element Method (Ansoft HFSS) and the other utilizing the Finite Integration Technique (CST Microwave Studio). The antenna was then fabricated and the performance measured using a Vector Network Analyzer (R&S ZVA-40). The simulated and measured reflection coefficients along with a photograph of the fabricated prototype are shown in Fig. 2.

As seen from Fig. 2, the simulated reflection coefficient stays below −10 dB from about 2.3 GHz to 6.7 GHz. The measured result is found to be in close agreement with the simulated one. A slight difference between the simulated results of CST Microwave Studio and HFSS software is seen and this may be because of the different methodologies used in the respective software. The S_{11} characteristic also shows dips (resonances) at 2.95 GHz, 4.9 GHz and 6 GHz (CST Simulation). Out of these, the first two resonances can be called the fundamental resonances where the lower one is decided by the slot dimensions, while the upper one is given by the monopole like operation of the feedline and the tuning stub. [21,22]. The overlapping of the two resonances is said to give the overall broadband behavior.

From the antenna description given above and shown in Fig. 1, the slot perimeter S_{per} and the stub height h_s can be calculated as

$$S_{per} = 2L + 2W - 2R_1 - 2R_2 + \frac{\pi}{2}(R_1 + R_2) \quad (1)$$

$$h_s = S + \sqrt{L_s^2 - \left(\frac{W_{s1} - W_{s2}}{2}\right)^2} \quad (2)$$

Following [12], the perimeter of the slot can be approximated to two guided wavelengths at the lower resonance frequency. It makes then, that the lower resonance frequency is given by

$$f_1 = \frac{2c}{S_{per}\sqrt{\varepsilon_{r,eff}}} \quad (3)$$

On the upper side, the monopole like operation of the antenna takes place and the upper resonance frequency can be given in terms of the stub height as

$$f_2 = \frac{c}{4h_s\sqrt{\varepsilon_{r,eff}}} \quad (4)$$