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A circularly polarized slot antenna for high gain applications

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ABSTRACT

A coplanar waveguide fed slot antenna for wideband circular polarization is designed and experimentally validated. The rectangular slot is excited using a stepped feed line terminated on a circular disc shaped tuning stub. To obtain circular polarization, inverted L-shaped strips are attached to the ground plane at the opposite corners while a rectangular slit is cut in the circular disc. The combined bandwidth (3-dB axial ratio and 10 dB impedance matching) achieved is 48% (4.35–7.1 GHz) under simulation and 40% (4.75–7.1 GHz) in measurement. The gain of the antenna is next enhanced by the application of a double layered square loop frequency selective surface. The frequency selective surface is used as a reflector placed beneath the antenna at an optimum distance. An improvement of about 4 dB is seen in the measured peak gain over most of the operating band. Experimental results are presented to characterize the antenna and the frequency selective surface and they are found to be in good agreement with the simulated results.

1. Introduction

There is an ever increasing demand to improve the data transfer rate and enhance the transmission quality of UWB wireless communication systems. In this respect, printed antennas with dual polarization and circular polarization characteristics can be used. A circularly polarized antenna allows for flexible orientation of the transceiver and also helps to combat multi-path fading effects in a diverse environment [1]. A number of printed antennas displaying circular polarization (CP) properties have been reported in the published literature. In particular, the coplanar waveguide (CPW) fed slot antenna is preferred for its cost efficient uniplanar structure and wider bandwidth. The uniplanar structure also reduces misalignment errors to a large extent [2]. In addition, the CPW feed is characterized by less dispersion, low radiation loss and ease of integration with monolithic microwave integrated circuitry. Some of the slot antennas recently reported for circular polarization are listed in Refs. [3–8].

Along with a desired polarization profile, another feature of the antenna quite important in several applications is the gain or directionality property. As against the microstrip fed antennas, the CPW fed monopoles or slots suffer from reduced gain due to the absence of a ground backing. The radiation patterns of these antennas tend to be omni-directional implying a wastage of power for applications such as point to point communications or object tracking. Other applications where the extended bandwidth of UWB is used such as microwave imaging, biomedical imaging, non-destructive detection and ground penetrating radars also require high gain or uni-directionality. The uni-directional feature also improves the signal to noise ratio. One solution to improve the gain of a CPW feed antenna is to provide a metallic reflector beneath the antenna which can also act as a shield for the adjacent electronic circuitry. However, the metallic shield causes image currents to appear and the out of phase reflections result in deterioration in the impedance matching and distortion in the far-field radiation patterns. Another solution is the application of a frequency selective surface (FSS) just like a reflector. The FSS is also called a high impedance surface (HIS) and when properly placed, can offer in-phase reflection over a wider band and improve the impedance matching. In other words, it can be used to enhance the gain and the bandwidth of an antenna [9–13].

In the work presented in this paper, a compact slot antenna utilizing CPW feed is designed. The geometry of the slot is a rectangle with perturbations applied for getting circularly polarized behavior. The CP bandwidth realized is 40% centered at 6 GHz while the impedance bandwidth attained is 121% (from 2.5 to 10.2 GHz). To improve the gain of the antenna, a frequency selective surface is designed and implemented. The FSS is a square loop printed on both sides of substrate and placed beneath the antenna to act as a reflector. The double layer is chosen since a multi layer FSS offers wider

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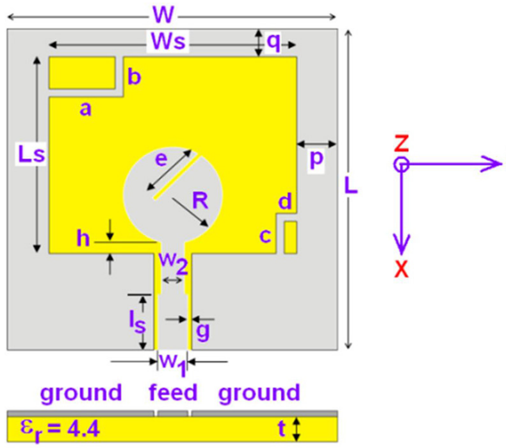

(a)

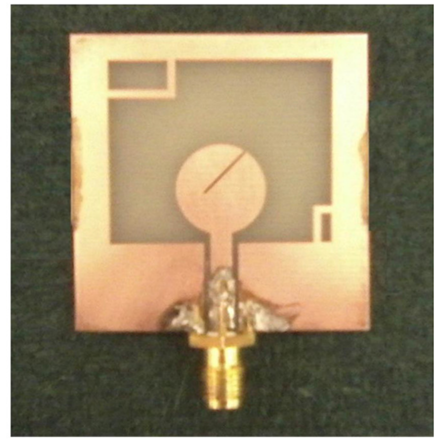
(b)

Fig. 1. (a) Geometry of the proposed antenna (b) fabricated prototype.

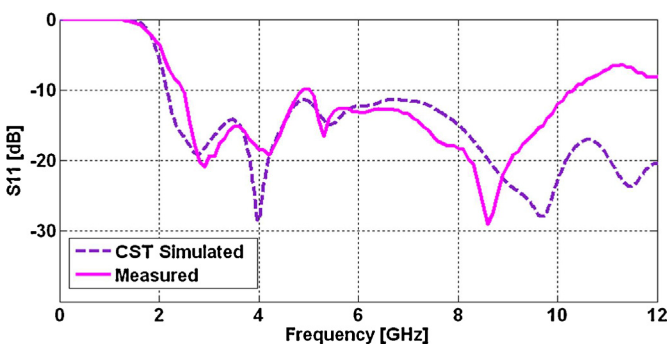

Fig. 2. Measured and simulated reflection coefficients of the proposed antenna. (For interpretation of the references to color in this text, the reader is referred to the web version of the article.)

bandwidth and sharper roll-off [14,15]. The gain improvement with the FSS antenna combination is around 4 dB. It is observed that with this FSS, though there is an improvement in the gain, there is a loss in CP bandwidth. To retain the CP bandwidth, another patch type FSS is designed and simulation results are presented. The software used for simulation is CST Microwave Studio (CST MWS) while measurements are taken using a Rohde and Schwarz Vector Network Analyzer (R&S-ZVA 40). In the following section, the antenna geometry is described followed by a section on simulated and measured results. Thereafter, the FSS design is described and the enhancements in the gain and the radiation patterns are discussed. Finally conclusions are made.

2. Antenna configuration

The geometry of the proposed antenna and its placement in the co-ordinate system is depicted in Fig. 1(a). A glass epoxy (FR4) substrate of relative permittivity $\varepsilon_r = 4.4$, loss tangent $\tan\delta = 0.002$ and thickness 1.58 mm is utilized for fabricating the antenna. The ground plane is printed on one side of the substrate and measures $W \times L$ mm^2. A rectangular slot is etched on the ground plane which has dimensions $Ls \times Ws$ mm^2. The width of the metallic strip surrounding the slot is '*p*' mm for the vertical section and '*q*' mm for the horizontal section. As seen from the figure, the rectangular slot is excited by a CPW whose feed line is two – stepped for better impedance matching. The widths of the two sections of the feed line are indicated by w_1 and w_2 whereas the length of the section closer to the port is denoted by 'l_s'. The feed is terminated on a circular disc shaped patch protruding into the slot center. The patch has a radius of '*R*' mm and works like a monopole. For obtaining circular polarization characteristics, inverted L-shaped strips, 1 mm wide are attached to the ground plane at the opposite corners of the rectangular slot. The lengths of the various sections of these strips are indicated by '*a*', '*b*', '*c*' and '*d*'. Further, a slant rectangular slit is cut in the circular disc. The slit measured 1 mm in width, 7.8 mm in length and is inclined at 45° with the vertical. All the parameters of the proposed antenna are listed with their values (in mm) in Table 1. A photograph of the fabricated antenna is shown in Fig. 1(b).

Table 1
Optimized antenna dimensions.

S. no	Parameter	Value (in mm)
1	L	40
2	W	40
3	Ls	24.5
4	Ws	30
5	p	5.0
6	q	3.5
7	R	6.0
8	W_1	3.6
9	W_2	2.8
10	a	9.0
11	b	5.0
12	c	5.0
13	d	2.5
14	e	7.8
15	g	0.5
16	h	1.2
17	t	1.6

3. Simulated and measured results

The proposed antenna was initially simulated on CST Microwave Studio and then fabricated with the optimized dimensions. The measured and simulated reflection coefficients are compared as shown in Fig. 2 and seem to be in good agreement. The impedance bandwidth seen from the simulated reflection coefficient (for $S_{11} < -10$ dB) starts from 2.2 GHz and extends well beyond 12 GHz. The measured S_{11} characteristic follows the simulated S_{11} however at higher frequencies (>9 GHz) the measured return loss increases due to the quality of the SMA connector employed and the measured impedance bandwidth is restricted up to 10.2 GHz. From the simulated reflection coefficient (dashed – blue line, Fig. 2), resonances can be noted at 2.75 GHz, 4.0 GHz, 5.4 GHz and 9.6 GHz. The first resonance is controlled by the wide slot of dimensions $Ws \times Ls$; the slot perimeter being approximately equal to one guided wavelength at this frequency. The circular disc at the end of the CPW line