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RESEARCH PAPER

High Gain Circularly Polarized S-Band Patch Antenna for Small Satellite Applications

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ABSTRACT

In this paper, a circularly polarized compact, high gain printed antenna is adduced for the small satellite communication system. For the analysis process, Computer Simulation Software (CST) microwave studio and High-Frequency Structural Simulator (HFSS) have been used. The anticipated antenna consists of a truncated corner cut patch with a T-shaped slot in the ground plane. CST and HFSS both simulation softwares have been justified the axial ratio and reflection coefficient result. The CST and HFSS simulated results show that the obtained impedance bandwidths are 130 MHz (2.30 -2.43 GHz) and 140 MHz (2.28 – 2.43 GHz) respectively which is good enough for S-band satellite applications. Substrate material FR-4 (lossy) with a dielectric constant of 4.6 and width of 1.6 mm has been used to print the antenna. An axial ratio of 3 dB beamwidth more than 160° displayed by the proposed antenna.

Key words: Circular polarization, high gain, satellite application, small antenna.

Introduction

Most of the application like global positioning and a radar system as well as wireless local area network currently uses circular polarization which has made this polarization one of the preferred polarization. A major system for circular polarization is not different though there are various kinds of circularly polarized antenna. Circular polarization(CP) for small satellite system is very much desirable to ease any orientation-relevant affairs of the acquiring base station antennas (Imbriale et al., 2012). In addition, a small satellite which is an invention of miniaturization technology without degrading performance has created an era in the satellite industry.

In the last decades, many studies have been developed for the small satellite antenna. With a fractional bandwidth of 1.5% and frequency at 2.225 GHz, a planar antenna for small satellites is developed (Tanaka et al. 1995). With the satellite size of 60 × 60 × 70 mm^3, another CP planar antenna of which profile and gain are ultimately low 2.4-GHz for an SSETI- Express minisatellite (Holmberg & Slater, 2002).For small satellite applications, a CP circular patch antenna fed by a coaxial probe operating within a tunable frequency range of 2.0-2.5 GHz was developed (Gao et al., 2009).

A patch antenna which is compact single layer co-axial probe-fed circularly polarized high-gain is designed for HORYU-4 nanosatellites S-band communication is presented (Islam et al., 2015). A circularly polarized S-band antenna for satellite application with parasitic elements around the main radiator is introduced (Choi et al. 2014) and this antenna design has a wide-ranging 5dB AR bandwidth of 12.3% as well as stable peak gain of 7.6dBic.The modification of circular shape patch by cutting circular shape slots for a highly directional circular polarized S-band patch antenna for satellite application that is small was proposed (Samsuzzaman et al., 2015). Simulation result shows the impedance bandwidth of 55 MHz (2.380-2.435GHz) and an axial ratio less than 3 dB is about 35 MHz (2.410-2.445GHz). A new compact single-fed circularly polarized S-band antenna for Nanosatellite Telemetry and Telecommand applications has introduced where the reflector is composed of an Artificial Magnetic Conductor (AMC) in order to decrease the size of the structure (Bellion et al., 2016).

A high gain circularly polarized S-band antenna for small satellite is presented in this article which is easy to fabricate and less expensive. Axial ratio bandwidth achieved from the antenna of 22 MHz with ±80 degree beam

Materials and Methods

Antenna Geometry

Implementation of the equations from the transmission line model (TEM), the primary geometry of the proposed patch antenna was first designed. Below equations can demonstrate the width and length of the patch antenna in relation to the detailed central frequency(Garg 2001):

$$W = \frac{c}{2f_o}\sqrt{\frac{\varepsilon_r + 1}{2}} \quad (1)$$

$$L = \frac{c}{2f_o\sqrt{\varepsilon_e}} - 2\Delta l \quad (2)$$

Where L and W are the length and width of the patch respectively, f_o is target resonance frequency, the speed of light in a vacuum is *c* and the relative permittivity can be measured by the equation:

$$\varepsilon_e = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r + 1}{2}\sqrt{(1 + \frac{10h}{W})} \quad (3)$$

Where the substrate width is h, and ε_r is the dielectric constant of the substrate. The antenna looks larger electrically comparing to physical dimensions due to the adjoining field around the boundary of the patch. Considering this result Δl can be stated as:

$$\Delta l \;= 0.412h\frac{(\varepsilon_r + 0.3)(\frac{W}{h} + 0.264)}{(\varepsilon_e - 0.258)(\frac{W}{h} + 0.8)} \quad (4)$$

The length of the probe feed is also measured as the antenna is fed with the probe feed. Probe feed line and the input impedance of the antenna should be matched. The antenna is firstly considered to operate in single frequency at S-band in account the design necessities such as dielectric constant and bandwidth and subsequently adjusted to achieve the most desirable size of the patch using HFSS and CST simulator. The design challenges for such applications differ from other modern wireless communications systems in that power consumption and size of the node are serious issues (Whyte et al., 2006). These limitations place strict requirements on the communication system; the system frequency should be high in order to minimize the antenna size. The proposed antenna's geometric layout is exposed in Fig.1. On FR-4 substrate material, the antenna is designed. Substrate wideness is 1.6 mm, relative permittivity is 4.6 and dielectric loss of 0.024. The antenna contains a square patch with two square slots on the one side of the substrate. The one square slot is etched out from the top right corner with length *Ls* and another slot is etched out from the down left corner with the same length. These two slots are responsible for creating resonance frequency on the particular frequency. On the other hand, a square ground plane with opposite T-shaped slot has etched out from the center of the ground plane. This opposite T-shaped slot is responsible for creating circular polarization. The optimized antenna parameters are given in Table 1 with their values.

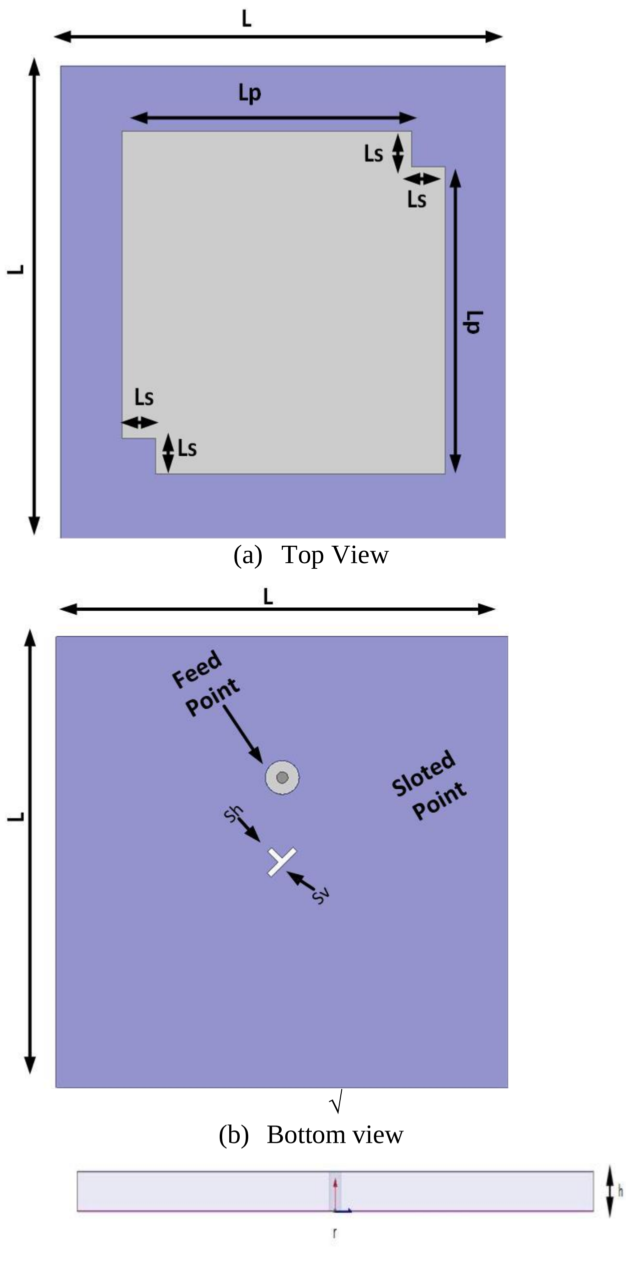

Figure 1. Geometry layout of presented antenna

Table 1. Proposed Antenna Specification with Different Parameters

Parameters	Values(mm)	Description
L	40	Length of ground plane
Lp	26	Length of patch
Ls	3	Length of area etched from patch
h	1.6	Height of substrate
Sh	1.15	Horizontal slot
Sv	1.13	Vertical slot
r	1.5	Radius of circle

Results and Discussion

The proposed antenna has been designed and studied by High-Frequency Structural Simulator (HFSS) and Computer Simulation Software (CST) microwave studio. The working procedure of these two software is Finite Integration Technique (FIT) as well as finite element method based respectively. Fig. 2 represents the reflection coefficient of the proposed antenna. It shows the simulated result of impedance bandwidth using HFSS and CST software and the results are 130 MHz (2.30 -2.43 GHz) and 140 MHz (2.28 – 2.42 GHz) respectively. Smith chart is used to detect all potential impedances on the domain of existence of the reflection coefficient. Smith chart of the antenna has been evaluated for impedance matching and this result is given in Fig. 3. Additionally, in Fig. 4 the axial ratio of the proposed antenna has been analyzed. The axial ratio indicates the antenna's polarization. An antenna can be called circularly polarized if the value of the axial ratio is less than 3 dB where the ideal circular polarized antenna's axial ratio value is 0 dB. The antenna displays 22 MHz of 3 dB axial ratio bandwidth which represents the antenna as circular polarized. So this antenna signal is more resistance due to atmospheric condition. Proposed antenna's current distribution experimented at 2.36 GHz.

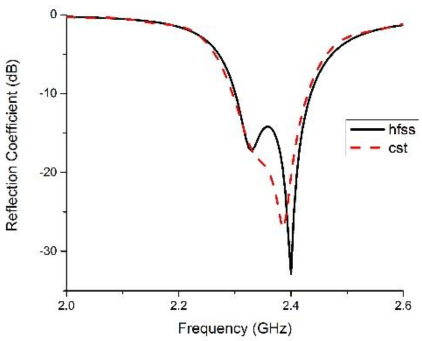

Figure 2. Simulated Reflection coefficient of the proposed antenna

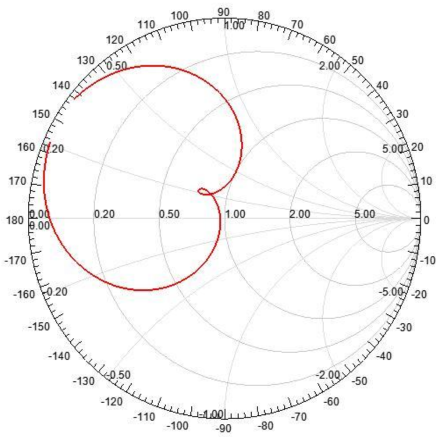

Figure 3. Simulated smith chart of the proposed antenna.

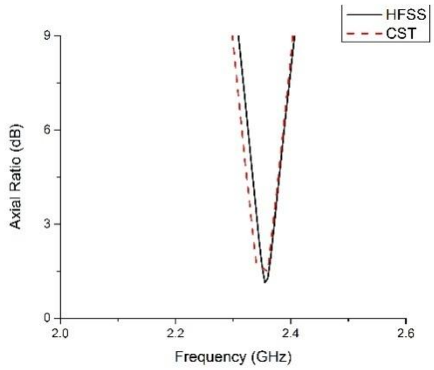

Figure 4. The simulated axial ratio of the proposed antenna.

The current spreading experiments at four phases 0°, 90°, 180° and 270° are illustrated in Fig. 5. Surface current distribution movement is anti-clockwise. Right-hand circular polarization (RHCP) has been observed from its behavior.Fig. 6 illustrates the elevation angle scope regarding lower 3-dB axial ratio for two different value of Phi and the value is 0 as well 90 respectively at 2.36 GHz. For Phi = 0 the lower 3-dB axial ratio is -80 degree and for Phi = 90 the value is +80 degree.

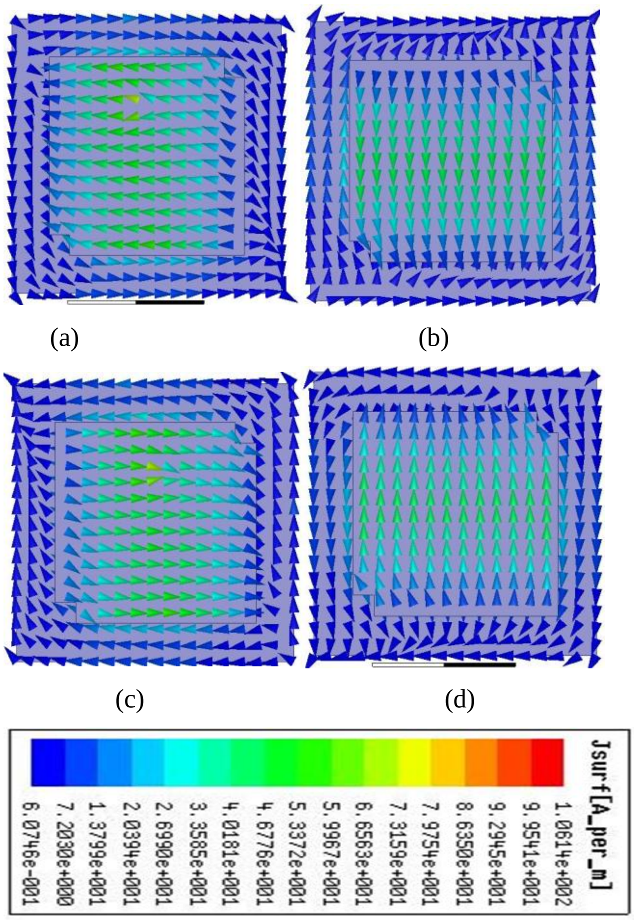

Figure 5. Simulated surface current distribution at 2.36 GHz for altered phases (a) 0° (b) 90° (c) 180° and (d) 270°

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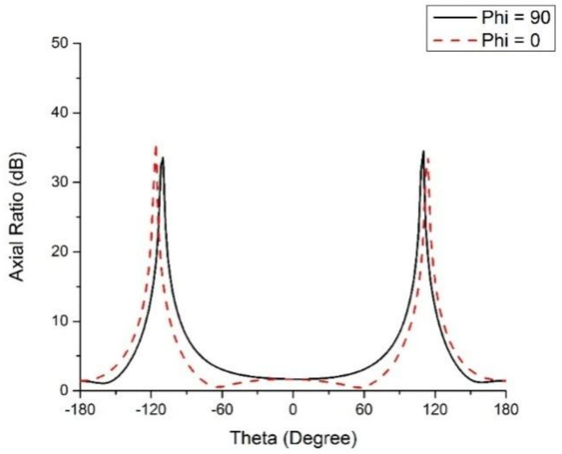


Figure 6. Simulated axial ratio pattern of the proposed antenna at 2.36 GHz

If the VSWR is under 2 the antenna match is considered very good and little would be gained by impedance matching. Figure 7 illustrates the VSWR curve of the proposed antenna which indicates the frequency range from 2.30 to 2.43 GHz is the calculated impedance bandwidth below 2. In Fig. 8 2D radiation diagram of the presented antenna is being analyzed. The simulated 2D radiation patterns of the proposed antenna are represented in Fig. 8(a), as well as in Fig. 8(b) at 2.36 GHz for phi 0 and 90 degree respectively. Core lobe direction displays at 0°. The antenna produces larger RHCP comparing to LHCP. The antenna's 3D radiation pattern shows the RHCP and LHCP performances in Fig. 9 and main lobe magnitude is 5.22 dB.

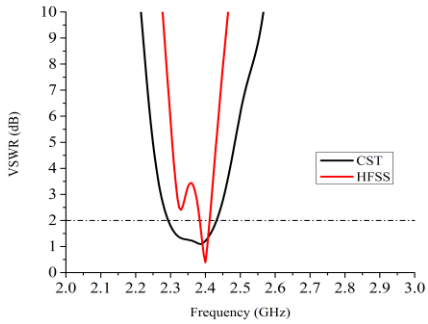


Figure 7. Simulated VSWR of the proposed antenna

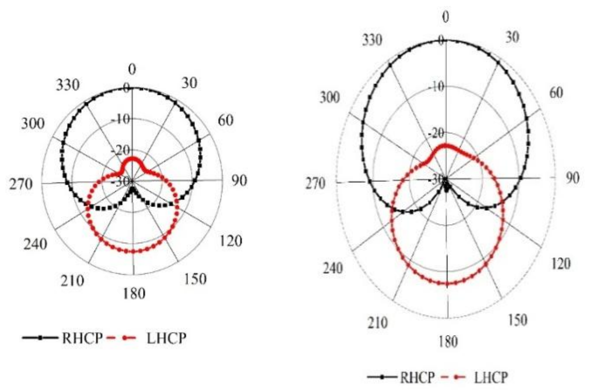
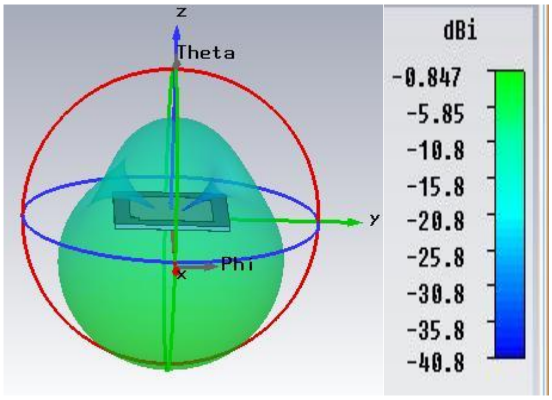
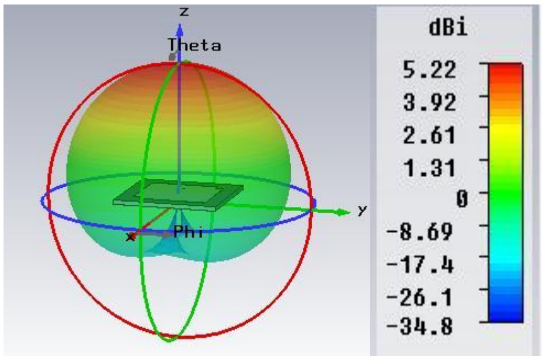


Figure 8. Simulated 2D Radiation Pattern at 2.36 GHz (a) Phi 0° (b) Phi 90°



(a)



(b)

Figure 9. Simulated 3D radiation pattern at 2.36 (a) LHCP (b) RHCP

Conclusion

A circularly polarized high gain patch antenna for S-band satellite application system has been introduced and its design, simulation result, and implementation are presented in this paper. The proposed antenna is easy to fabricate as well as less expensive. An antenna can be said to be circularly polarized when the axial ratio value is less than 3 dB where the ideal value of axial ratio proposed antenna is circular polarized. This antenna found to have an S_{11} of more than -32.915 dB at 2.4 GHz. This type of antenna is capable of transmitting at high gain with maintaining its low profile structure which is very much desirable for a small satellite. Therefore for the respective satellite application, the proposed antenna can be worth enough which can also be used for another frequency as well. In future, the proposed antenna will be fabricated and the actual result will be measured as well as simulation effect with the actual satellite will be examined in the same condition of space.

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