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A Wideband Stacked Patch-Patch Antenna with Hybrid Perturbations for Circular Polarization

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Abstract— **This paper presents a wideband circularly polarized antenna for small satellites to be used with NASA Near-Earth Networks (NEN). This single-fed stacked antenna utilizes the electromagnetic coupling concept and is usable with a duplex transceiver. The circularly-polarized antenna employs hybrid perturbations on stacked patches and covers NASA NEN's both uplink and downlink frequencies, thus replacing the conventional requirement of two separate antennas. It provides a notable wide axial ratio (AR) < 3 dB bandwidth of 1.16 GHz from 7.02 GHz to 8.18 GHz (15.3%). The optimized patch dimensions provide 34.6% VSWR ~ 2 bandwidth from 6,525 MHz to 9,253 MHz. The overall antenna size is 17 mm × 17 mm × 6.6 mm, and has a peak gain of 7.9 dBi. This proposed antenna will overcome solar cell space constraint on smallsat's outer wall by saving at least 50% area required by the conventional two-antenna method.**

Keywords—Small Satellite, circular polarization, wideband, axial ratio

I. Introduction

Modern small satellites started its era of large-scale industrial revolution. Multiple versions of miniaturized small satellites from femto-satellites to micro-satellites are being used commercially as well as for research and military purposes [1]. A state-of-the-art small satellite having advanced capabilities calls for mature components within smaller area. The structure and system engineering teams of any small satellite mission always face the challenges that arise from limited surface area for installing solar cells and antennas. They always prefer to keep more space for solar cells as one of the biggest challenges for any small satellite mission is power positive operation. On-board antennas also need direct line of sight communication with the ground station antennas, so antennas also need to be placed on the outer surface. This issue urges communication engineers to look for the least space occupying antenna combination. It is a challenging task to cover both the allocated uplink and downlink frequencies with a single antenna. Moreover, like large satellites, small satellites need circular polarization as linearly polarized antennas need strict orientations [2]. Apart from these, embedded system designers of small satellites always prefer single feeding over dual feeding antennas for the simplicity of the system.

Ref. [3- 4] provide solutions of a single antenna with dual-band and wideband circular polarization radiation for CubeSats (Smallsat) for their uplink and downlink communications using NASA Near Earth Network (NEN) and NASA Deep Space Network (DSN). The user guide of the NASA NEN ground stations [5] list all their transmitting and receiving frequencies. Overall, NASA NEN's X-Band receiving frequencies varies between 7,500 – 8,500 MHz while the transmitting frequencies are 7,025 MHz to 7,200 MHz [5]. Here, a stacked antenna with hybrid perturbations has been proposed that provides wideband CP performances covering NASA NEN's uplink and downlink frequencies.

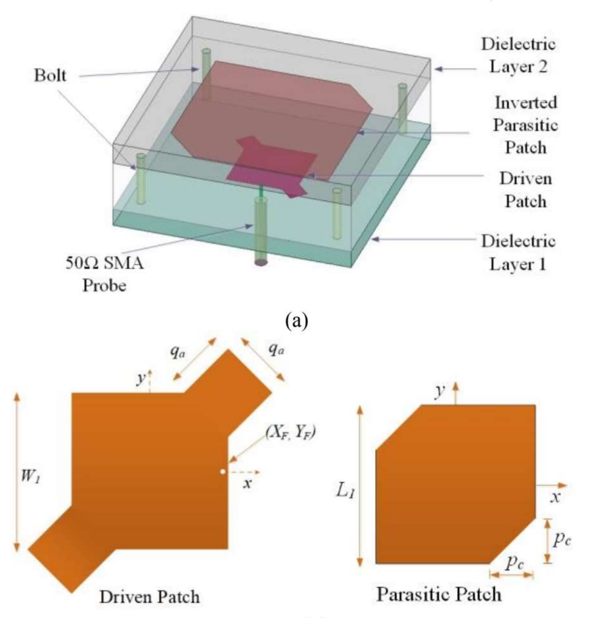

Fig. 1: (a) Proposed antenna, (b) geometry of the driven and parasitic patch with hybrid perturbations

II. Antenna Geometry

The proposed planar stacked antenna follows a similar design technique described in [6], though uses different hybrid perturbations. Fig. 1(a) shows the 3D antenna geometry with air gap and coaxial feeding. A 50Ω coaxial probe feeding is used over the line feeding with a tuning stub upon application preference. The antenna contains three 35 µm-thick copper layers, two different dielectric laminates and an air gap of 3.7 mm. The first dielectric laminate is Rogers RT/duroid 6010 with 1.27 mm thickness and relative permittivity of 10.2. The antenna's return loss and circular polarization performance highly depend on this. The ground plane is the first metal layer that uses a 35 µm-thick copper layer. The driven patch is a square patch with positive perturbations along diagonally corners and it is excited by a 50Ω SMA probe at a point 2.3 mm away from the center of the patch. The third copper layer is an inverted parasitic patch on the second dielectric layer: Rogers RT/duroid 5880 with a thickness of 1.575 mm and relative permittivity of 2.2. The Parasitic patch does not have any wire connection, but it is electromagnetically coupled to the driven patch. Table I lists the dimensions and Fig. 1(b) describes the geometry of the patches used in the design. The ground plane size determines the overall antenna size which is 17 mm × 17 mm. Circular polarization is achieved by adding corner stubs to the driven patch and applying negative perturbations on the opposite diagonal corners of the parasitic patch.

TABLE I. THE DESIGN PARAMETERS OF THE PROPOSED ANTENNA

Driven Patch size (mm)	Driven Corner Perturbation (mm)	Parasitic Patch (mm)	Parasitic Corner Perturbation (mm)	Probe Position (X_F, Y_F) (mm)
W_1= 4.9	q_a = 1.3	L_1= 12	p_c= 2.4	(2.3, 0)

III. Results

The antenna optimization procedure aims to achieve wide impedance and axial ratio bandwidths that supports both uplink

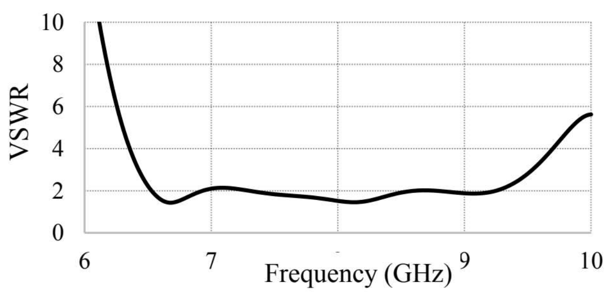

Fig. 2: Simulated VSWR versus frequency plot

and downlink operation for any small satellite which intends to use NASA NEN ground stations. A series of parametric studies on patches, perturbations, air gap, and feed point aiming to adjoin the resonances generated by driven and parasitic patches enables the wideband operation. Ansys HFSS 2020, a finite element method (FEM)-based simulation tool is used to design and simulate the antenna. A wide bandwidth for VSWR ~ 2 is obtained from 6,525 MHz to 9,253 MHz (2,728 MHz or 34.6%), as shown in Fig. 2. The simulated axial ratio < 3 dB bandwidth is 7,020 MHz to 8,184 MHZ (1,164 MHz, 15.3%). Based on the polarization rotation direction, there are two types of circularly polarized antennas: Right-Hand Circularly Polarized (RHCP) antennas, and Left-Hand Circularly Polarized (LHCP) antennas [7]. The proposed antenna is a RHCP antenna and it has a peak gain of 7.9 dBic. Fig. 3 shows the simulated axial ratio and RHCP gain versus frequency plots of the antenna. For this

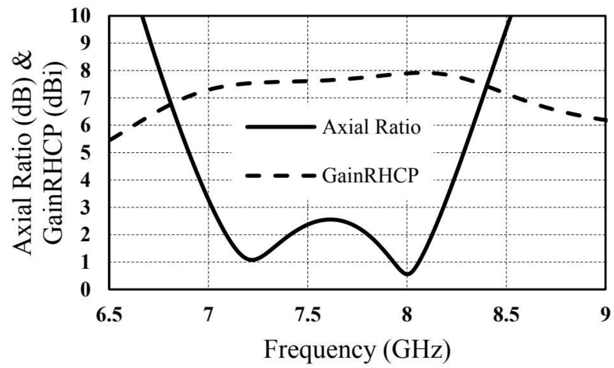

Fig. 3: Axial ratio and RHCP gain versus frequency plots

antenna, the driven patch dominates the first axial ratio minima region while the parasitic patch dominates on second axial ratio minima region of the spectrum. The antenna shows wide AR beamwidths in both $\varphi = 0^0$ and 90^0 planes. At the first minimum AR frequency (7,226 MHz), the beamwidth is 77^0 (-29^0 to $+48^0$) in the $\varphi = 0^0$ plane, and 116^0 (-52^0 to $+64^0$) in the $\varphi = 90^0$ plane. These values are 109^0 and 105^0 respectively in $\varphi = 0^0$ and 90^0 planes for the second minimum AR frequency (8,000 MHz). The 3 dB RHCP gain beamwidths are around 76^0 to 84^0 in those planes at the first and second AR minimum frequencies, respectively.

IV. Conclusion

The proposed circularly polarized antenna shows a wide 3dB axial ratio bandwidth of 15.3%, covering the uplink and downlink frequencies of NASA NEN. This antenna is advantageous for small satellites in terms of high gain, small size and wideband operation. This will save the space of at least one extra antenna allowing more room for additional solar cells, which should improve the power management of smallsats.

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