Multi-Band CubeSat Antenna and Design Considerations for Space Environment

Rifaqat Hussain(1), Abdullah Al-Garni(1), Sheikh S. Iqbal(1), and Qammar H. Abbasi(2)

(1) Electrical Engineering Department, KFUPM,
Dhahran, 31261 Saudi Arabia, *email:*{*rifaqat,algarnia,sheikhsi*}*@kfupm.edu.sa*
(2) James Watt School of Engineering,
University of Glasgow, Glasgow, UK, *email:*{*Qammer.Abbasi@glasgow.ac.uk*

***Abstract*—In this paper, a slot-based multi-band CubeSat antenna is designed for CubeSat applications operating at the UHF band. The proposed antenna design consists of a frequency reconfigurable (FR) slot-based antenna fabricated on a FR-4 substrate. The frequency range covered by the FR antenna is 300-450MHz. A single varactor diode is used to sweep the frequency of the design. The proposed meandered loop-slot antenna design is small in size and has planar geometry with overall substrate dimensions of 100×100 mm^2. The proposed antenna with frequency reconfigurability is ideally suited for small satellite applications in the UHF band, especially CubeSats.**

I. Introduction

Cube Satellites, or CubeSats, are indeed a type of Nanosatellite that has lately acquired popularity, particularly among those who see CubeSats as a developing alternative to conventional satellites for space initiatives. This is due to their low cost and ability to be manufactured using commercial off-the-shelf components. A CubeSat must have a minimum size of 1U (100×100 mm^2). The 1U is easily upgradeable for usage in larger missions (2 to 12U). A CubeSat undertakes all of the essential activities of a traditional satellite. Its power requirements are fulfilled by a battery pack and solar panels affixed to the CubeSat's body. However, as CubeSats are smaller in size than traditional satellites, their subsystems must be tiny. Furthermore, antenna design is a critical component of satellites including downstream and upstream communication between ground stations and satellites. However, its size and weight must be compatible with the CubeSat and must give good radiation performance [1].

The number of antennas for CubeSats that operates at 437 MHz, i.e. the amateur UHF band, has expanded recently, which not only allows for seamless uplink and downlink communication but it also allows one CubeSats to interconnect with each other in a network. Furthermore, CubeSat antenna configurations in the UHF range provide both planar and non-planar geometries. Numerous planar and non-planar antenna configurations appropriate for CubeSats that operate in the UHF band have been published in the literature including slot, dipole, monopole, helical, Yagi-Uda, and meander-line antennas. Patch and slot antennas are the greatest alternative for linking CubeSats in orbit with ground stations on Earth because of their reduced size, compactness, resilience, and simplicity of manufacturing. They also have minimal radiation loss, lower dispersion, and simple matching of input impedance [2] .

Various slot-based antennas with planar configurations have been highlighted in the literature [3]–[6]. They are operating at UHF, L, S, C, and X bands. In the solution provided in [3], an inductor is used to shorten a slot line with an electrical length of lambda/4. The proposed design operated at 300 MHz with dimensions of 5.5× 5.5× 0.787 cm3. The main disadvantage of this architecture is its small bandwidth (4.8 MHz). The authors in [**?**] showed the integration of two meander-line slot antennas working at up and downlinks, which were subsequently cascaded to produce a 3U CubeSat. The antennas work at UHF frequencies of 485 MHz and 500 MHz, respectively. The gain and reflection coefficients for the presented design in the UHF band (485 and 500 MHz) are 2.73 dB and -13.6 dB and -15 dB for uplink and downlink, respectively. The desired frequency may be obtained by carefully adjusting the meander parts. In [5], a miniaturized meander line antenna for CubeSats is presented at 920 MHz. The size of the antenna is 50 × 80 × 1.635 mm3 with a gain of 1.8 dB. [6] a slot-based antenna at 401MHz with 8MHz bandwidth is presented. The proposed design has dielectric board dimensions of 76.6 × 162.25 mm^2. A gain of 5.2 dBi and a return loss of -31dB were achieved.

The proposed antenna is a highly miniaturized slot-based design with frequency reconfiguration. The FR slot-based antenna is intended for a 100×100 mm^2, 1-unit, of the CubeSat surface. Miniaturization is achieved in the structure by folding a meandering slot-line structure. The proposed antenna is distinguished by its compact size, planar geometry, and frequency reconfigurability. The slot is 50×68 mm^2 in size. It operates in the UHF frequency range of 300-450MHz and is ideal for CubeSat applications.

II. Operating Environment and Implication on CubeSat Antennas Operation

The most crucial elements that affects the CubeSat hardware and antennas are the following:

- Space radiation in low earth orbits
- Low earth orbits' thermal stress
- Low pressures in low earth orbits

Based on the study conducted in [7], the above items are identified as the critical elements to be investigated further and mitigated for proper operation of CubeSat hardware specifically antennas. According to the standard IPC-4101, rigid PCB design with dielectric constant are required for better signal integrity, a greater transition glasses (T_g) and a lower coefficient of thermal expansion (CTE). According to the standard ECSS-Q-ST-70-12c, the mostly used materials for PCB design in space applications are FR4 and Roger 4000 series. FR-4 has a T_g up to 180^oC and RO4000 series material has a T_g $>180^o$C and CTE of 19 to $17 ppm/C$ thermal expansion and are best suited for hazardous space environments.

III. Design Details

The proposed meandered loop slot-line antenna design is shown in Fig. 1. The antenna was developed and built on FR-4 substrate with surface area of $100\times100\text{mm}^2$. The substrate's relative permittivity (ϵ_r) is 4.4 and its loss tangent (tanδ) is 0.03. Post optimization, the antenna design consists primarily of the following elements: an etched slot-line structure from the ground plane and a meandered-shaped hexagonal slot-line employed to improve the radiating structure's effective electrical length.

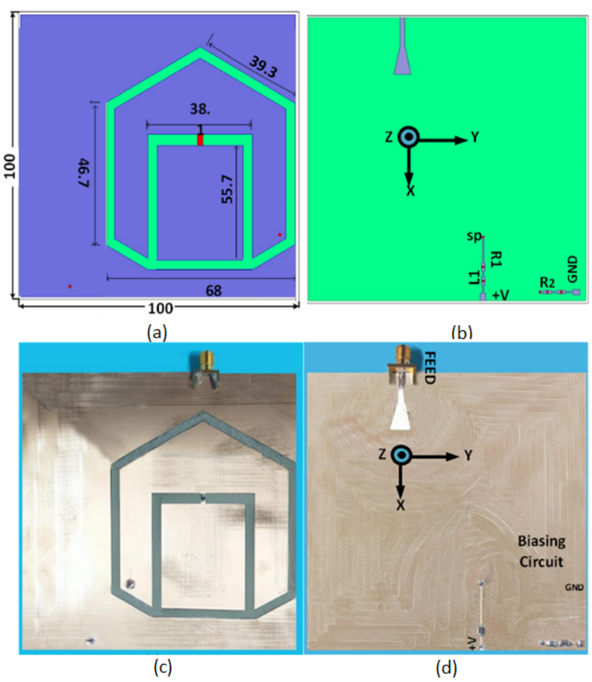

Fig. 1. Proposed antennas (a) Top view (b) Bottom view.

Fig. 1(a) depicts a detailed view of the proposed antenna top layer while Fig. 1(b) shows the ground plane. It is made up of a matched 50Ω input impedance (Z_{in}), a microstrip feedline, and the varactor diode's biasing circuitry. The varactor diode biasing circuit (Dv) was made up of a series of RF choke (L_1 and L_2) and current limiting resistor combinations (R_1 and R_2). Sorting posts (SP) were utilized to connect the bottom layer varactor diode to the top layer biasing circuitry. To separate the radiating structure from the power source, RF chokes were utilized. The reverse-biased varactor diode acted as a DC blocking capacitor. Hence, the DC biasing part and the RF radiating structure are well isolated and have a very minimal effect on the antenna's performance.

IV. Results and Discussion

The proposed antenna design was characterized for scattering parameters. Figs. 2(a) and 2(b) depict the simulated and measured reflection coefficient curves (S_{11}) for the proposed antenna design. The curves produced for the design have varactor diode capacitance values ranging from 1.32∼9.63 pF and reverse bias voltage values ranging from 15 to 0 V. From 300∼450 MHz, a smooth change in the resonating bands was detected, with a -10 dB bandwidth of 17 MHz.

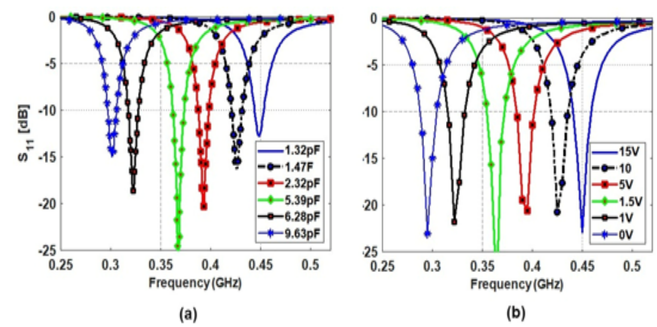

Fig. 2. Reflection Coefficient (a) Simulated S_{11} (b) Measured S_{11}

V. Conclusions

The proposed meandering loop slot-line antenna is appropriate for CubeSat applications. To function in the UHF band, the provided antenna was optimized utilizing bending, meandering, and reactively loading the slot approaches. The proposed antenna was built on a FR-4 substrate of dimensions 100×100 mm^2. The antenna's small planar construction, capacity to operate over a wide band of the UHF frequency range, and narrow-band functioning are unique aspects of this design.

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