Novel Load Bearing Antennas for CubeSat Applications

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ABSTRACT

Increasingly, CubeSat and Small Satellite platforms are used for space exploration and Earth science remote sensing from LEO locations. Due to their low cost and fast deployment time, CubeSat platforms are also employed for new technology development and technology readiness level (TRL) maturation in the space environment. RF antennas are essential components of these CubeSat/Small Satellite platforms used for communication and remote sensing radars/radiometers. Types of antennas currently used on CubeSat/Small Satellite platforms include; monopole/dipole antennas; printed antennas; printed antennas integrated with a solar cell; and antennas printed on the backside of solar cell. These types of antennas need a packaging and deployment mechanism; hence, their use poses a deployment failure risk to a mission. Furthermore, these types of antennas add extra volume and weight to the payload. A novel load bearing antenna concept for CubeSat/Small Satellite platforms that does not need packaging or a deployment mechanism, thus eliminating the risk of deployment failure is presented.

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INTRODUCTION

CubeSat and small satellite platforms because of their low cost and fast development time are often used for validation and for advancing TRL of new space technologies. This trend has intensified activities in the development of miniaturized technology components that are compatible as far as the weight, volume and power constrains dictated by the small satellite and CubeSat platforms. RF antenna is one of the key component technologies onboard CubeSats used for telemetry, high-speed data downlink, radars and RF remote sensors.

Types of antennas (as shown in Figure 1) currently used on these platforms include; reflector antenna [1], printed antennas [2], monopole/dipole [3] etc. When planned to be used for the CubeSat applications, these antennas need packaging and deployment mechanism. Use of these deployment mechanisms increase the risk of failure during the mission, and subsequently asks more attention during design, integration and testing of the CubeSat. Furthermore, this system adds extra mass to the CubeSbat and it takes up space that could be used by other subsystems. The novel embedded antenna design presented in this paper does not need packaging or a deployment mechanism, thus not only reducing the risk of deployment mechanism failure but eliminate such risk.

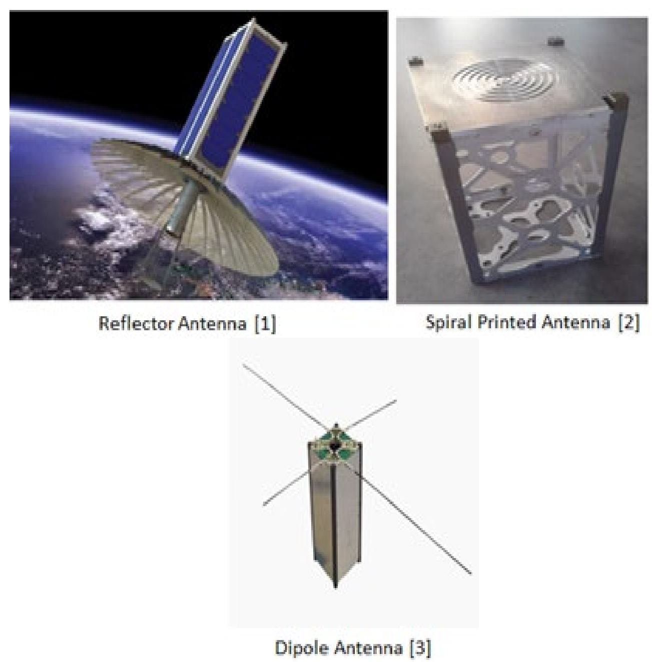

Figure 1 Some of antennas currently used for CubeSats applications

Basic Concept

Figure 2 shows a basic bus structure of a 1U CubeSat with four rectangular railing at its four corners to

support the bus structure. Currently the railing structure is made of solid rectangular rods. In addition, solid metal sheets are used to form multiple sides of a CubeSat bus structure. Assume that instead of using solid rectangular railing rods, we use a hollow tube (as shown in Figure 3) with either rectangular or circular opening. Such replacement will obviously give advantage in reducing the overall weight of a CubeSat. However, more importantly, these hollow tubes can be used as microwave transmission lines to carry RF signals. When a series of radiating rectangular slots (Figure 3) are cut on these microwave transmission lines, these hollow tubes will be serving as a RF antenna.

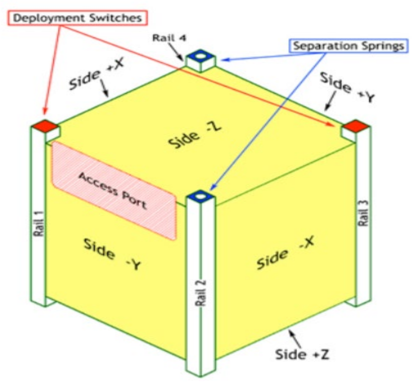

Figure 2 Basic bus structure of 1U CubeSat

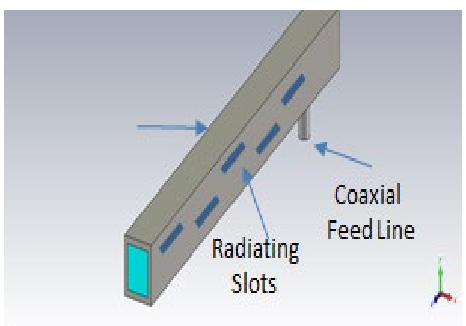

Figure 3 Hollow railing with radiating slots

In addition to use of railing as a structure bearing antennas, the CubeSat bus manufacturers also use solid metal sheets to form multiple sides of a CubeSat bus structure. These solid metal sides can be embedded with multiple rectangular openings as shown in Figure 4. Each of these rectangular opening can be used as rectangular waveguide transmission lines to carry RF signal. When a series of radiating slots are cut on the one of the sides of each rectangular waveguide, the metal siding can be used as a planar array antenna

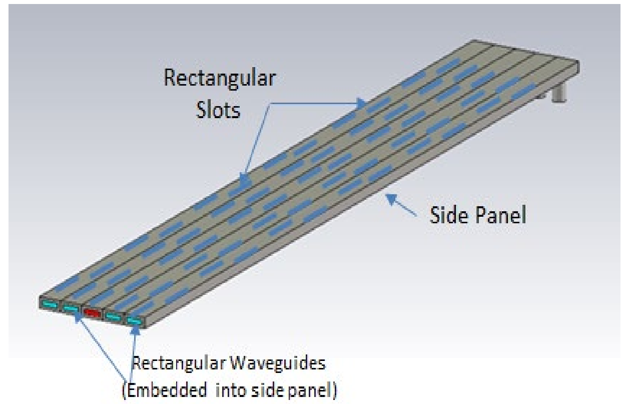

Figure 4 A CubeSat side panel with embedded rect. waveguides with radiating slots

If a is the broad wall dimensions of rectangular opening, then the cut-off frequency, f_c for the dominant TE_{10} mode for such rectangular waveguide is controlled by its dimension a ($f_c = C/2a$, [4]) where C is the speed of light). Hence, by properly selecting the dimension a, it is possible to use such hollow rectangular railing as a microwave transmission line for desired operating frequency. It may be noted that it will be challenging to use these small size railings $(1cmx1cm)$ to accommodate transmission lines to carry lower frequencies. Such challenge can be overcome by filling the rectangular opening with a high dielectric constant medium. Likewise the side panels of a CubeSat bus can be embedded with multiple rectangular openings of appropriate sizes to be used as parallel microwave transmission lines as shown in Figure 4.

A custom designed coaxial to rectangular waveguide transition as shown in Figure 1(b) can be used to launch the TE_{10} mode.

This rectangular waveguide carrying a TE_{10} mode can be made to radiate microwave energy at a desire frequency by cutting either series or parallel radiating slots either on its broad or narrow walls. Furthermore, a linear array of radiating slots can be cut on these rectangular waveguides to form a linear slot array or planar array as shown in Figures 3 and 4.

DESIGN OF LINEAR SLOT ARRAY

For the purpose of demonstration and experimental validation we select inner dimensions of rectangular opening as 2.23 x 1.02 cm. Also for our design we select operational frequency at $f_0 = 11GHz$. From this information we can estimate its guide wavelength using [4]

$$\lambda_g = \frac{C}{f_0} \frac{1}{\sqrt{1-(C/(2af_0))^2}} = 3.4468cm \qquad (1)$$

Considering a 6U platform, the length of railing bar available for the slot array is around 30 cm. 3 cm of total 30 cm length will be used for launching TE_{10} mode into the rectangular opening. Hence, the total length available for the slot array is around 27 cm.

Usually for the slots to be fed in phase, inter-element spacing is set to $\lambda_g / 2$. Hence, the number of slots that can be accommodated over the total length of $L = 27cm$ is obtained from $N = Int(2L/\lambda_g) \approx 15$.

Slot Displacement

The coupling between the slot and incident TE_{10} mode is controlled by the slot displacement from the waveguide centerline. For uniform excitation the displacement is given by [5]

$$du = \frac{a}{\pi}\sqrt{\sin^{-1}(\frac{1}{N*G})} \quad , \quad \text{where}$$

$$G = 2.09\frac{a\lambda_g}{b\lambda_0}\left[\cos(0.464\pi\frac{\lambda_0}{\lambda_g} - \cos(0.464\pi)\right]^2 \qquad (2)$$

For $a = 2.23, b = 1.02$, $\lambda_g = 3.4468cm$, and $\lambda_0 = 2.7272cm$, needed displacement $du = 0.58cm$.

Slot Length and Width

To be resonant at $f_0 = 11GHz$, the slots with length equal to $l = 0.98 * \lambda_0 / 2 = 1.34cm$ and width = 0.16cm are selected. With these dimensions, the simulation model using the CST Microwave Studio to compute the slot array antenna performance was created. Also using the same dimensions, a prototype model as shown in Figure 5 was fabricated.

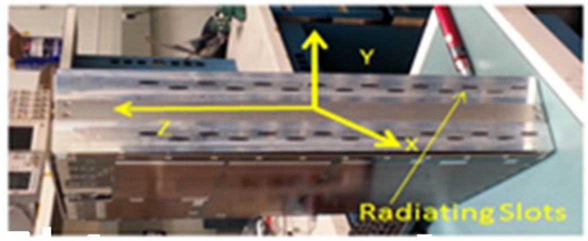

Figure 5 X-band slot array antennas on a mockup 6U

EXPERIMENTAL VALIDATION

Figure 6 shows computed and measured input VSWR of the linear slotted array as a function of frequency. It needs to be noted that the formulas used in estimating the array dimensions were based on an analytical formulation and hence are approximate. Once the array dimensions were selected, numerical simulation was performed using commercial electromagnetic simulation tool (such as CST Microwave Studio). Figure 6 shows an excellent agreement between measured and simulated results around the frequency of operation

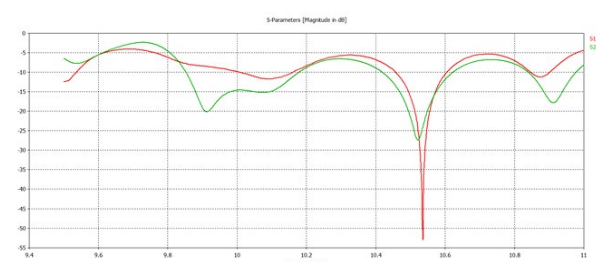

Figure 6 Measured (red) and computed (green) S11 (dB)

Figures 7(a) and 7(b) show computed radiation patterns in the YZ and XY planes Since there two more linear slot array on the backside of the CubeSat (not visible in Figure 5) Figure 7(a) shows a strong back lobe. Also in the XY plane, the radiation pattern is almost omnidirectional.

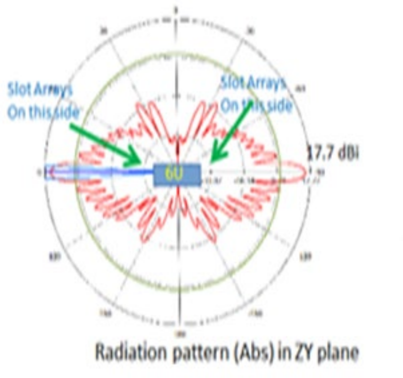

Figure 7(a) Computed Radiation pattern in ZY plane

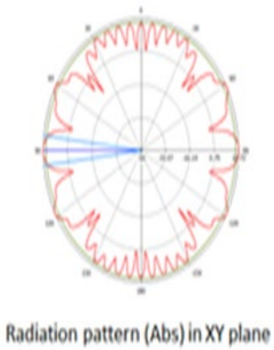

Figure 7(b) Computed radiation pattern ib XY plane

CONCLUSIONS

A novel load bearing embedded antenna concept for CubeSat and small satellite platforms has been successfully demonstrated. The proposed antennas do not need packaging or a deployment mechanism, thus eliminating the risk of deployment failure. It also helps reducing the weight and volume of payload to meet weigh and volume constrains imposed by these small platforms. This technology has been patented by NASA Goddard Space Flight Center and interested in licensing to private industry.

ACKNOWLEDGEMENT

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