A 6-40 GHz Antenna System for CubeSat Radiometer

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***Abstract* — A high-gain 6-40 GHz circularly polarized antenna system has been designed for a CubeSat Radiometer Radio Frequency Interference (RFI) Technology Validation mission, which is to demonstrate wideband (6-40GHz) RFI mitigating backend technologies vital for future space-borne microwave radiometers. In stowed configuration, the antenna system needs to fit within a small volume of 10cm (L) by 8cm (W) by 5cm (H). The deployed length of the antenna is 25cm. The total antenna payload including deployment mechanism needs to be less than 0.2kg. The desired gain is 14 dBic gain at 6 GHz and linearly increased to 22 dBic at 40 GHz in order to minimize the coverage footprint on earth. The proposed antenna system include three continuous-taper helical antennas due to its simple feeding, circular polarization (CP), and wide bandwidth. They also have desirable light weight and flexible structures. The three helical elements operate at 6-11 GHz, 11-22 GHz and 21-40 GHz, respectively. The diameter of each helical antenna is specially profiled as a function of height to achieve the desired linear gain vs. frequency property. Since the three antenna elements are co-located within a small cavity, their positions were carefully investigated to minimize mutual coupling and coupling to cavity. This paper presents the antenna design specifications, simulated performances, and preliminary measurement data.**

Index Term: CubeSat, Satellite, Helical Antenna, Radiometry, Wideband, RFI, Coupling

I. INTRODUCTION

Satellite microwave radiometers have been providing measurements of key environmental variables since the late 1970s. However, recently, these radiometers are facing the increasing risk of the man-made interference (RFI) [1]. To help the future radiometer extract a clean geophysical signal even in bands polluted by RFI. CubeSat Radiometer RFI Technology Validation (CubeRRT) mission (Figure 1) was proposed for the demonstration of successful real-time RFI mitigation in the global RFI environments over a broad set of frequencies covering the commonly used bands that have been impacted by RFI. This technology impacts all future space-borne microwave radiometer systems, and may even be required for all such missions as the availability of spectrum for scientific use continues to degrade. To achieve this goal, the specific antenna performance requirements are listed below:

Bandwidth Coverage: 6GHz to 40 GHz

Polarization: Circular Polarization (CP)

Gain: > 14dBic (40^o HPBW) at 6 GHz
>22dBic (16^o HPBW) at 40 GHz

Storage Space: 8cmx9cmx5cm

Weight: <0.2kg

Considering the above requirements, axial-mode helical antenna [3][4] appeared to be a natural choice for its simple feed, CP, wideband, light weight, and flexible structure. Typical optimized uniform helical antennas can achieve bandwidth of up to 1.6:1 [3], which is obvious not enough to cover from 6 to 40 GHz. There is also design tradeoff between bandwidth and gain. In order to use minimum number of helix antennas while achieving the desired gain, three tapered helical antennas are chosen for covering 6-11 GHz (BW~1.83:1), 11-21GHz (BW~1.9:1) and 21-40 GHz (BW~1.9:1), respectively.

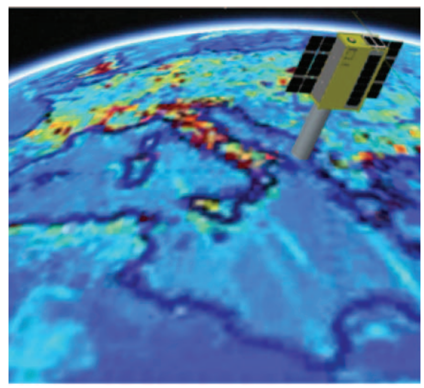

Figure 1 - Artistic rendering of CubeRRT observing 10.7GHz RFI over Europe (RFI image from GMI V-pol Observation [2]).

The helical antenna is firstly constructed as the uniform diameter. However, the bandwidth of this kinds of helical antenna are limited. To increase the bandwidth to achieve the desired 1.9:1, non-uniform diameter tapered helical antenna can be used [3][5][6]. Especially, the conical version of tapered helical antenna can achieve the bandwidth about 2:1[6][7] However, conical helical antennas produce constant over frequency. To achieve the desired linear gain over frequency, we adopted a quasi-taper helical antenna design, which is the combination of a uniform helical section in the top region and a conical helical section in the base region. This kind of antenna is a tradeoff between uniform diameter helical antenna and the conical helical antenna. Thus, it have a larger bandwidth like conical. It can be optimized gain at the high end like the uniform diameter helical antenna.

The impedance of a uniform helical antenna is about 140Ω [8], which is very inconvenient to connect to the backend. Several techniques have been developed for reducing the impedance to 50Ω[8]-[10]. Among them, tapered pitch of the first turn [10] is most attractive since it is simple to implement and does not add the extra weight.

Section II discusses about the details of the proposed linear gain helical antenna design based on quasi-taper helix. Section III presents the impedance matching process as well as simulation and measurement results. Final conclusions are given in Section IV

II. LINEAR GAIN HELICAL ANTEENNA DESIGN

A. Single Antenna Performance

For the same height H and same pitch distance S, compared to the uniform diameter helical antenna, the conical helical antenna sacrifice the gain for wider bandwidth as demonstrated in Figure 3 where it shows that the conical helical antenna has fairly constant gain over its operating bandwidth, as expected from its scaled antenna geometry.

In order to obtain the desired unique linear gain vs. frequency property with gain linearly increases (in dB) from low frequency end to high frequency end, we adopted a quasi-taper helical antenna design which consists of a uniform diameter section in the top region and conical section in the base region as shown in Figure 2. The base conical region is used to realize the wide bandwidth, the top uniform-diameter is used to increase the gain at high frequency end.

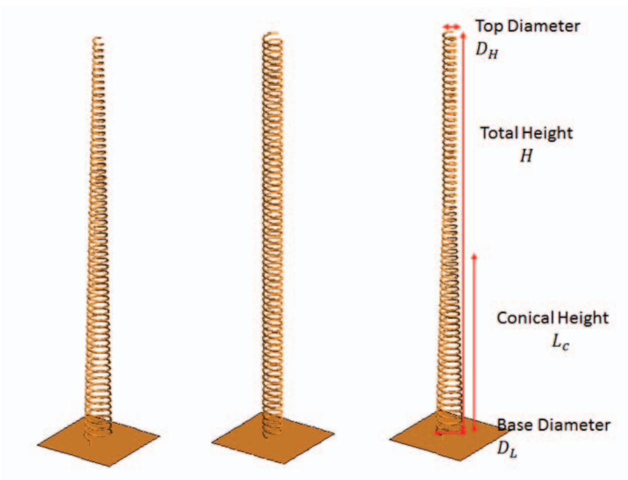

Figure 2 - From left to right: conical helical antenna, uniform diameter helical antenna and non-uniform helical antenna

Figure 3 compared simulated boresight gain of three different kinds of LHCP helical antennas: uniform helix, conical helix, and quasi-taper helix. All of them are 25cm long, and mounted on a 5cmx5cm ground plane, and have the 0.4cm pitch. These results show that the uniform helix can produce highest gain but over a much smaller bandwidth. The conical helix produces a lower gain than uniform helix, but over a 3-dB bandwidth of 2:1. The quasi-taper helix produce a gain that increase roughly linearly (in dB) with frequency over a very wide bandwidth, although it is somewhat difficult to define bandwidth for this special gain profile. The actual design parameters for the low band, middle band and high band quasi-taper helical antennas are listed in table 1.

B. Assembled Antenna System Performance

The numerical model of the final assembly of the antenna system is shown as Figure 5. Careful study of antenna position arrangement were conducted to minimize the coupling among antenna elements and between anteennas and small cavity. The final arrangement is shown in Figure 5. To validate the positioning choice, we compare the simulated boresight gain obtained from individual helical antenna along in cavity and that obtained when all three elements are presents in Figure 6. As one can see that only the gain at the lower end of the lowest band decreases by approximately 1 dB due the antenna mutual coupling.

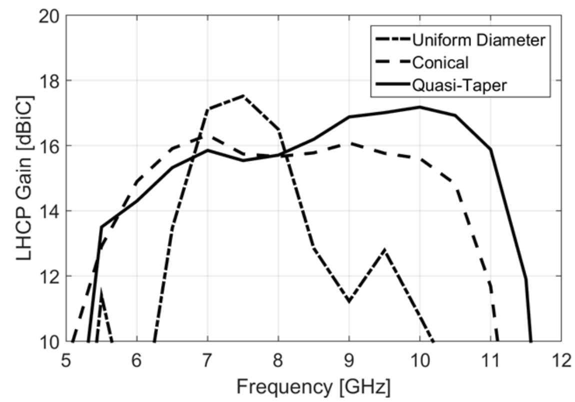

Figure 3 - Simulated boresight LHCP gain of the uniform diameter helical antenna, conical helical antenna and the quasi-taper antenna system.

TABLE I. OSU QUASI-TAPER LINEAR GAIN HELICAL ANTENNA DEISGN PARAMETERS.

cm	Low Band	Mid Band	High band
H	25	25	25
L_C	14	12	12
D_L	0.75	0.4	0.195
D_H	0.36	0.18	0.1
S	0.4	0.2	0.15

Figure 4 shows the simulated half-power beamwidth vs. frequency of the CubeRRT antenna system with three quasi-taper helical antenna elements.

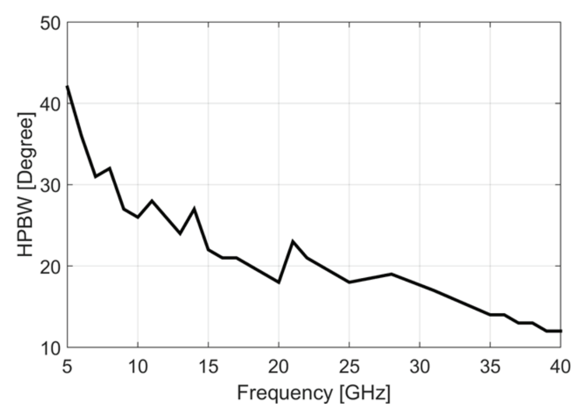

Figure 4- Simulated HPBW versus frequency.

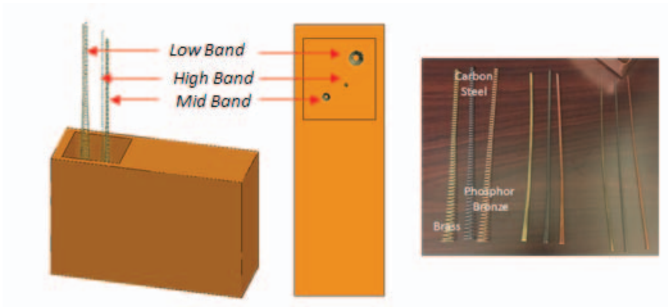

Figure 5 – (Left) CubeRRT antenna system on 6U CubeSat (Right) Fabricated quasi-tapered helical antenna elements made of different conducting materials: copper, brass, and steel.

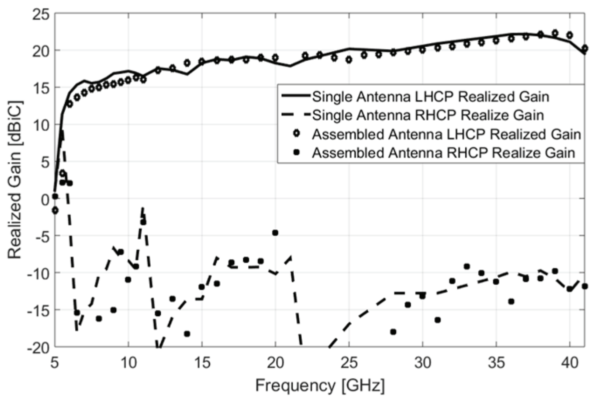

Figure 6- Simulated boresight realized gain of the single antenna and the assembled antenna system.

III. Fabrication and Testing

As mentioned, we achieve the 50Ω impedance matching by adjusting the pitch of first turn and the feed height. The Smith chart shown in Figure 7 depicts how the pitch of the first turn influence the antenna impedance. As the first-turn pitch increases, the resistance of antenna increases, and the reactance of the antenna decreases. The Smith chart shown in Figure 8 and the reflection coefficient shown in Figure. 9. depict how the feed length influence the antenna impedance and matching when S1=6mm. It is seen that iincreasing feed height leads to the increase of antenna resistance.

Based on the study discussed above, we concluded that the best matched result for the low-band antenna is when (d=0mm, s1=6mm). The corresponding reflection coefficient data is shown in Figure 9.

The same process was also used to optimize the mid-band and high-band antenna matching design. It was found that (d=0mm, s1=4mm) is the optimal design for the mid-band antenna and (d=0mm, s1=3mm) is the optimal design for the high-band antenna. Figure 10 shows the ssimulated and measured reflection coefficient data of mid-band and high-band antennas.

Simulated LHCP and RHCP gain patterns at some sample frequencies are also plotted in Figure 11.

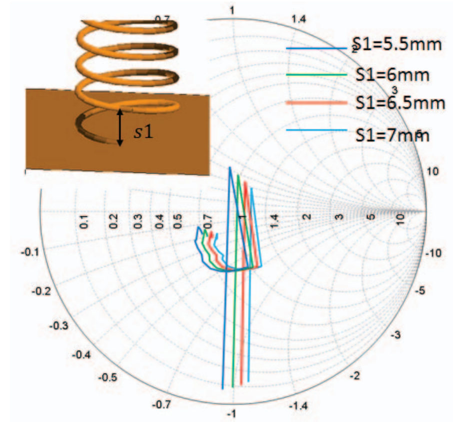

Figure 7 - Simulated helix impedance for different pitches in the first turn.

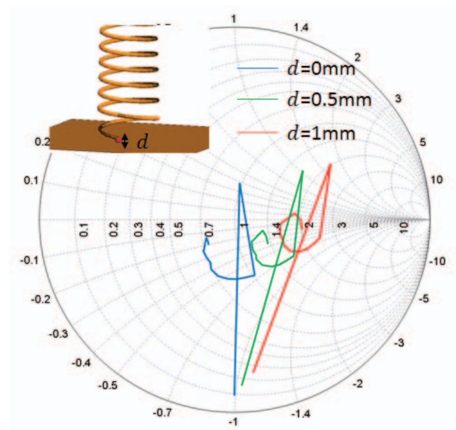

Figure 8 - Simulated helix impedance for different vertical feed heights.

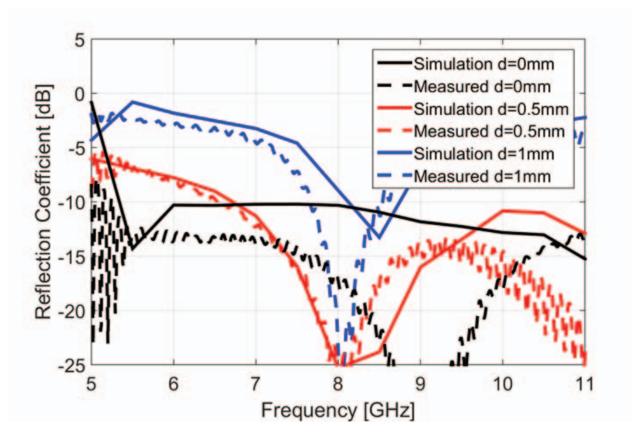

Figure 9 – Simulated and measured reflection coefficient data of low-band antenna for different feed heights.

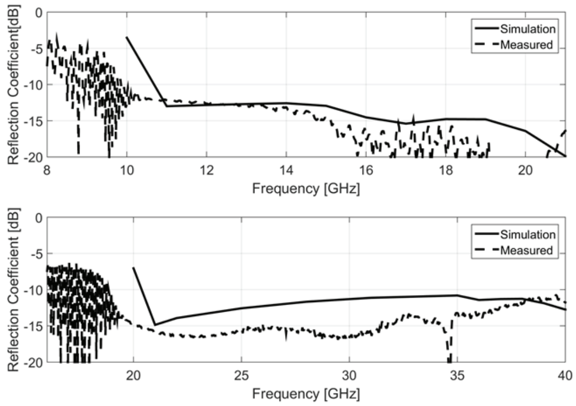

Figure 10 - Simulated and measured reflection coefficient data of mid-band and high-band antennas.

IV. Conclusion

We present a novel 3-element antenna system design for a 6U CubeSat mission for operating from 6 to 40 GHz with a linearly increasing (in dB) gain. Quasi-taper helical antenna elements were chosen to achieve the engineering tradeoff between the bandwidth and desired linear gain. Prototype antennas were fabricated at very low lost using commercial standard string making machine. Preliminary reflections coefficient measurement data obtained from the prototype agree well with the simulation results. Based on simulation results and limited measured data available to date, the proposed antenna system should be able to meet our Cube RRT mission antenna performance requirement.

References

[1] Spectrum Management for Science in the 21st Century, M. H. Cohen and A. J. Gasiewski (co-chairs), National Research Council, 2010.

[2] D. Draper, "Report on GMI Special Study #15: Radio Frequency Interference," *System Engineering Report 2444347*, Ball Aerospace Corporation for GPM Project at NASA's Goddard Space Flight Center. 1/16/2015.

[3] J. D. Kraus and R. J. Marhefka, *Antennas: For All Applications*, Third Ed., McGraw-Hill, 2002

[4] Balanis C A. *Antenna theory: analysis and design*, John Wiley & Sons, 2016

[5] J. Wong and H. King, "Broadband quasi-taper helical antennas," *IEEE Trans. Ants. Prop.*., 27(1): 72-78, 1979

[6] J. S. Chatterjee, "Radiation field of a conical helix,". *Journal of Applied Physics*, 24(5): 550-559, 1953

[7] H. Barsky, "Broadband conical helix antennas," *1958 IRE International Convention Record*, New York, NY, 138-146, 1959

[8] J. Kraus, "A 50-ohm input impedance for helical beam antennas," IEEE Trans. Ants. Prop., 25(6): 913-913. 1977

[9] V. Wongpaibool, "Improved Axial-Mode-Helical-Antenna Impedance Matching Utilizing Triangular Copper Strip for 2.4-GHz WLAN," 2008 International Wireless Communications and Mobile Computing Conference, Crete Island, 869-873. 2008

[10] D.E. Baker, "Design of a Broadband Impedance-matching Section for Peripherally Fed Helical Antennas," Antenna Applications Symposium. 1980

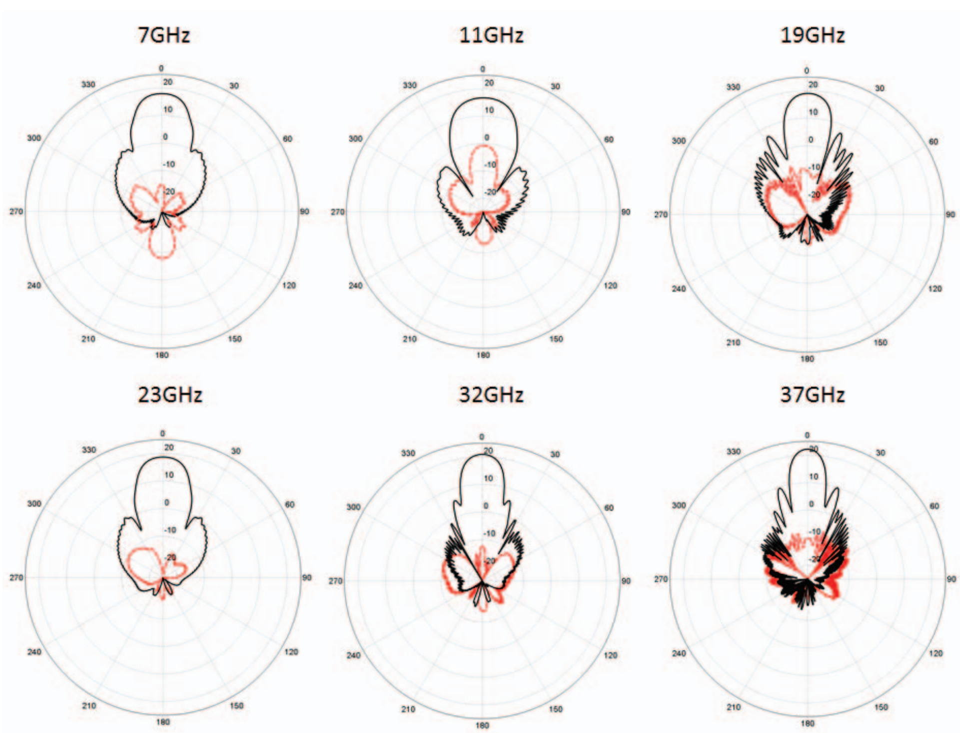

Figure 11 - Simulated pattern @ 7GHz, 11GHz, 19GHz, 23GHz, 32GHz and 37GHz. The Black Solid Line is the LCHP; The Red Dash Line is the RCHP