A Wideband F-shaped Patch Antenna for S-band CubeSats Communications

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Abstract— A wideband S-band F-shaped patch antenna is proposed for CubeSats communications. To broaden bandwidth, it uses two arms with different lengths to generate a second resonant frequency. The effect of the arm length and width on the return loss, resonant frequency and impedance bandwidth on a 3U CubeSat is studied. The simulation results show that the antenna achieves a wideband of 1121 MHz (1.606-2.727 GHz) with a return loss below -10 dB over the entire frequency band from 1.606 to 2.727 GHz. The antenna has a high gain of 8.51 dB and a small return loss of -32.85 dB at 2.45 GHz.

***Index Terms* — CubeSats; circularly polarized; axial ratio; gain**

I. Introduction

CubSats are revolutionizing the space industry and are critical for space research [1]. They have a mass ranging from 1.3 to 6 kg and a fixed face size of 10cm×10cm with three different lengths: 10cm, 20cm, and 30cm [2, 3]. Fig.1 shows an example 3U (10cm×10cm×30cm) CubeSat that is currently under development at the University of Wollongong (UoW). Compared to conventional satellites, CubeSats have a short development period of about one year and provide low cost access to space [2]. One advantage of CubeSats is that several dozens of CubeSats can be placed in a single launcher tube. To date, CubeSats are used for remote sensing applications [1, 4], including monitoring deforestation and agriculture yield, mapping and geospatial services, emergency responses, tracking of ships, and they are also used to aid oil exploration by processing and analysing satellite images of the Earth's surface [5].

CubeSats require a wideband high gain antenna for communications between satellites and a ground station. This antenna provides a link with a ground station for uplink telecommands as well as a downlink to send telemetry and data (images). The main design challenges are the limited size and low mass of CubeSats. This means any designed antenna must satisfy the size constraints of CubeSats.

To address the aforementioned challenges, patch antennas are ideal because they have a low profile, lightweight, are mechanically robust and are easily integrated with electronic devices [2]. In addition, they are available commercially for a variety of frequency spectrums including the popular high bit-rate 2.4-2.5 GHz unlicensed Industrial, Scientific and Medical (ISM) band. However, they have narrow bandwidth and low gains at high frequencies; i.e., 2.40-2.50 GHz [6]; both of which decrease data bitrate.

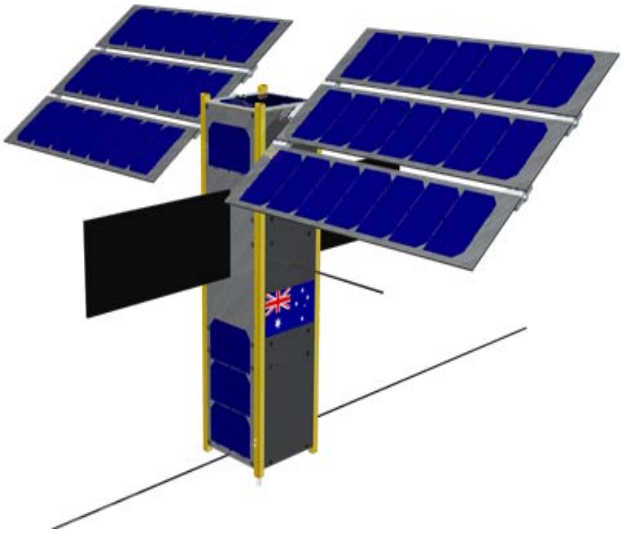

Fig. 1. UoW's 3U cube satellite (10cm×10cm×30cm).

There are many approaches to widen the bandwidth of patch antennas. One common technique is to use U-slot and L-slit patch antenna geometries. The main idea is to incorporate a folded inner small patch within a larger patch. The authors of [7] reported a bandwidth enhancement of 53.54% (3.57-6.18 GHz) at the resonant frequency of 4.5 GHz

and 45.12% (4.26-6.75 GHz) at 5.5 GHz. However, their main limitation is the resulting low gains of about 2.5 dB. Another approach is by interleaving two patch antennas [8]. The main idea is to use a folded ramp-shaped feed and one pin in the centre of the upper patch to increase bandwidth. The authors also used shorting pins between the patches and the ground plane to miniaturize the antenna's size. Although the modified S-band shorted patch antenna presented in [8] has a wideband of 320 MHz (2.200-2.520 GHz), its size is reasonably large at 83×83 mm^2, making it unsuitable for used on CubeSats.

In this paper, we propose a wideband 2.45 GHz F-shaped patch antenna for CubeSats communications. The main idea is to feed the resonance arms of the upper F-shaped patch by a folded ramp-shaped patch. This generates two resonant frequencies and hence achieves a wide bandwidth. Moreover, three shorting pins between the edges of the upper patch (F-shaped patch) and the ground plane are used to increase the effective electrical length of the patch and hence reduces its physical size. In addition, shorting pins are also used to lower the resonant frequency and widen bandwidth. Compared to all previous S-band planar antennas, see our survey in [2] and listed in Table 1 for convenience, our design achieves a higher gain, i.e., 8.51 dB, has a wider bandwidth of 1121 MHz (1.606-2.727 GHz) and has small size of 33.8×88.4 mm^2, which means less surface area on a CubeSat; i.e., 29.8% for 1U and 14.9% for 2U.

Table 1. Comparison between S-band patch antennas for CubeSats and our proposed antenna

Ref.	***Antenna Type***	***Gain [dB]***	***Bandwidth [MHz]***	***Size [mm^2]***
[9]	Four-element microstrip patch array	7.1	320	15×15
[8]	Shorted patch antenna	3.51	320	83×83
[10]	Patch antenna	n/a	80	80×80
[11]	Circular patch antennas	5.96	50	3.14×1.2^2
[12]	Wire patch antenna	n/a	116.34	3.14×2.7^2
Proposed antenna	**F-shaped patch**	**8.51**	**1121**	**33.8×88.4**

II. Antenna Design and Structure

Fig. 2 shows the structure of the proposed antenna. It consists of an upper F-shaped patch, a folded patch feed and three shorting pins. The antenna uses the CubeSat's surface as a ground plane with air substrate. It is fed by a 50 Ω coaxial probe at (x_0, y_0) and supported by the three shorting pins that are connected between the upper F-shaped patch and ground plane. These shorting pins generate low resonant frequencies and hence increases bandwidth and help reduce the size of the antenna. The diameter of the shorting pins that provides the optimal antenna bandwidth is 3.64 mm Moreover, to reduce the coaxial probe length and inductance at the feed section, the folded patch technique [13] is used and fed at a height of h_1= 18.4 mm. The length of the arm L_1 and the width of the slot W_2 are studied using the High Frequency Simulator Structure (HFSS) [14] to obtain their optimal value. These parameters play a significant role in enhancing the antenna's performance; i.e., bandwidth, resonant frequency and return loss. They also produce two resonant frequencies and hence improve bandwidth. The optimal parameter values of the proposed antenna are as follows: h_1= 18.4 mm, h_2= 9.5 mm, L=33.8 mm, W= 88.4 mm, W_1= 20.8, W_2= 15.6, W_3= 36.4 mm, L_1= 20.8 mm, L_2= 23.4 mm, L_3= 10.4 mm, L_4= 13 mm, x_0= 0 mm and y_0= 10.4 mm.

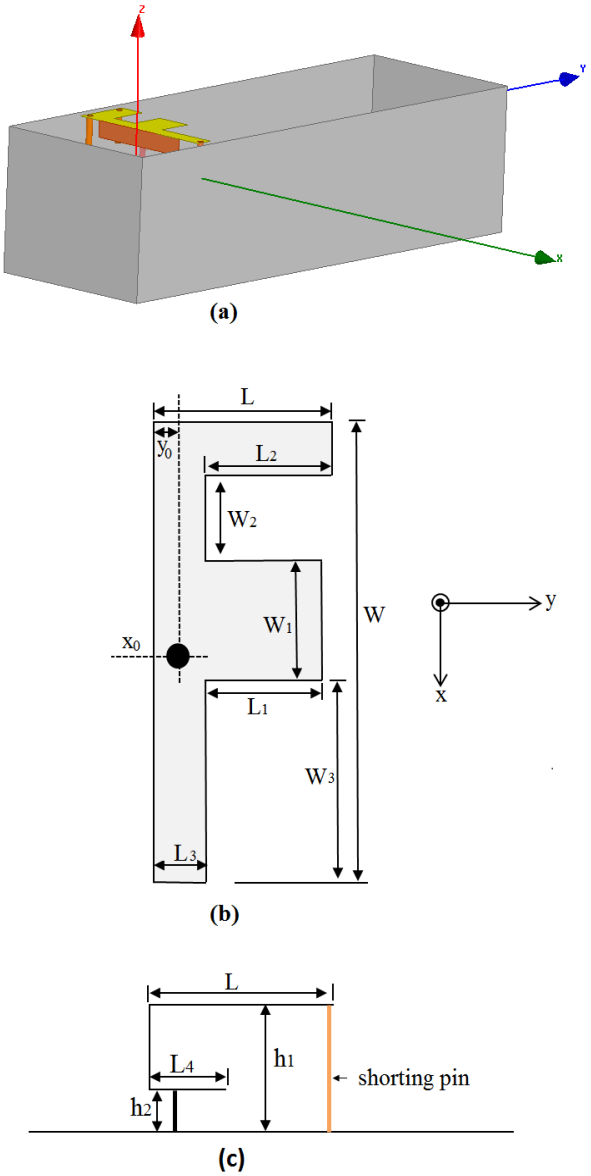

Fig. 2. Configuration of the wideband F-shaped patch antenna. (a) a 3D view of the proposed antenna as modeled in HFSS on a 3U cubeSat, (b) top view, and (c) side view.

III. Results and Discussion

The simulation results are obtained using HFSS. Fig. 3 shows the simulated return losses of our F-shaped patch antenna with the following L_1 lengths: 18.8, 20.8 and 22.8 mm. Other parameters are fixed. We can see that the second (fundamental) resonant frequency increases when the length of L_1 increases while the first resonant frequency is barely

affected. The required resonant frequency of 2.45 GHz is obtained at L_1=20.8. Moreover, when L_1 is set to 18.8 mm, the F-shaped patch antenna becomes a dual-band antenna rather than wideband. The most suitable length is L_1= 20.8 mm as it provides wide bandwidth; i.e., 1121 MHz, and small return loss of -32.85 dB at resonant frequency 2.45 GHz. This means good impedance matching.

Fig. 4 shows the simulated return loss of the proposed antenna with different slot width values and L_1 =20.8 mm. The width W_2 is varied from 8.6 to 22.6 mm. We see that the slot width W_2 has no effect on the resonant frequency and the bandwidth of the F-shaped patch antenna. However, the return loss S_{11} increases when the width W_2 decreases. In addition, when W_2 is set to 22.6 mm, a dual band resonant mode is obtained. Hence, small -10 dB impedance bandwidth, i.e., 600 MHz (2.12 – 2.72 GHz) is achieved. The most suitable width is W_2 = 15.6 mm as it provides an impedance bandwidth of 1121 MHz (1.606-2.727 GHz) and a small return loss of -32.85 dB at resonant frequency 2.45 GHz. This means large bandwidth, high bitrate, low reflected power and good impedance matching; see Fig. 4 and 7.

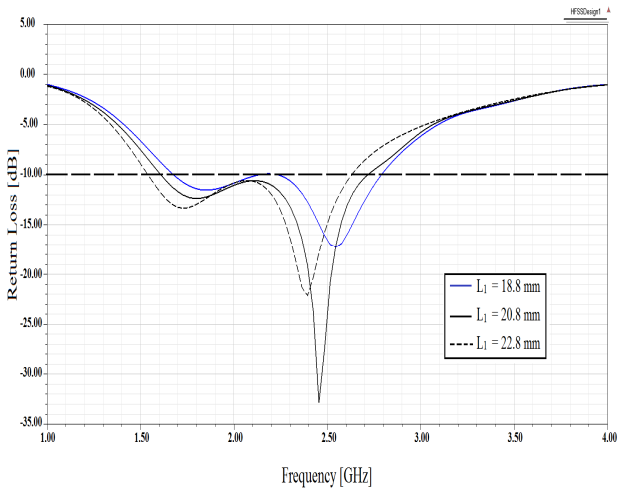

Fig 3. Simulated return loss against frequency for various L_1

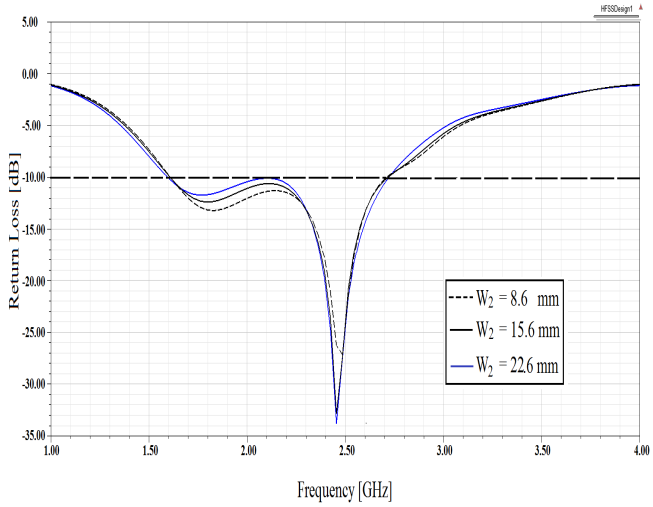

Fig. 4. Simulated return loss against frequency for various W2

Fig. 5 and 6 show the 3D and 2D simulated radiation pattern at the resonant frequency of 2.45 GHz. The back lobe is significantly reduced because we use a large ground plane (CubeSat's surface) and hence a unidirectional pattern is achieved. This is important as it increases the total gain and decreases the interference with the electronics inside the CubeSat. The maximum achieved gain is about 8.51 dB with a 20^0 elevation tilt and Half Power Beamwidth (HPBW) of 98.34^0 at a resonant frequency of 2.45 GHz.

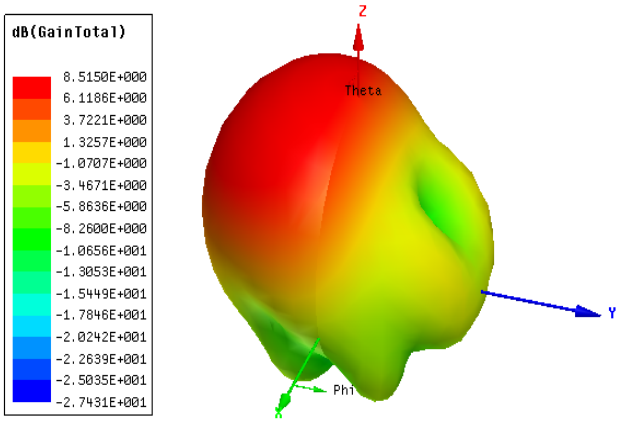

Fig. 5. 3D gain at 2.45 GHz.

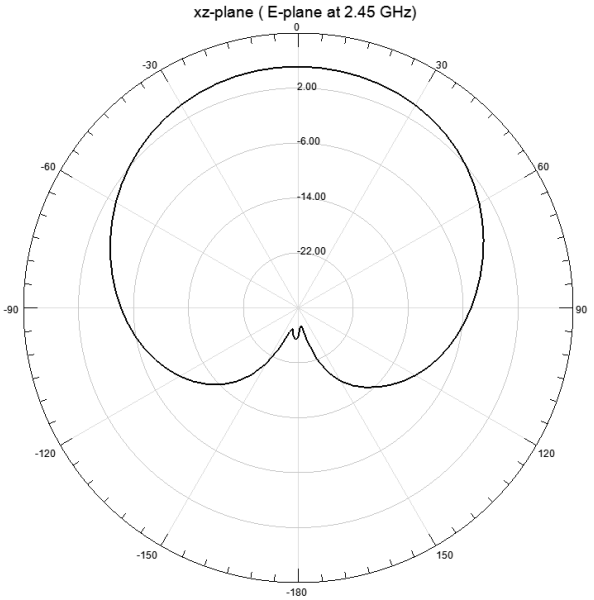

Fig. 6. Simulated radiation pattern of F-shaped patch antenna at 2.45 GHz

Fig. 7 depicts the simulated input impedance (real and imaginary parts) of the F-shaped patch antenna in the 1 – 3.5 GHz frequency bands. We note that good impedance matching is obtained at 2.45 GHz with almost 50 Ω real part and zero imaginary parts (inductance). The input impedance (real and imaginary parts) is 50+j0 Ω at the resonant frequency of 2.45 GHz. This means very small reflection with most power radiated into space.

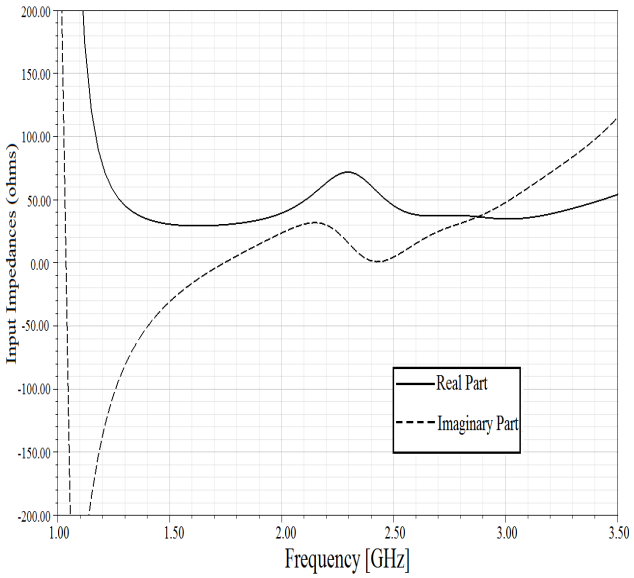

Fig. 7. Input impedance of the proposed antenna

IV. Conclusion

We have proposed a wideband F-shaped patch antenna for S-band CubeSats communications. The simulated return loss is below -10 dB from 1.606-2.727 GHz (bandwidth= 1121 MHz). The antenna size is small; i.e., 33.8×88.4 mm^2. Simulated results show it has a resonant frequency of 2.45 GHz, a small return loss of -32.85 dB, a high gain of 8.51 dB and good impedance matching of 50 Ω.

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