Design and Analysis of a Compact Meander Line Antenna for CubeSat

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***Abstract*— Small satellite is one of the most growing sectors in space industries and is widely used by the universities to increase the experience of space researchers and students. The antenna is an important component that is used to determine the size of the satellite system. This paper introduces the design and implementation of a miniaturized printed Meander line monopole antenna having a volume of (80mm×50mm×1.67mm) and operating at 429 MHz centre frequency. The antenna is fabricated on FR-4 substrate with dielectric constant of (εr = 4.3) and thickness of 1.6 mm. The proposed antenna consists of three parts which are different in length to have a maximum size reduction to be suitable for the CubeSat size, and a rectangular shape to give a good impedance matching. The comparison between the simulation and measurement results are presented. A return loss below -10db and bandwidth of 6MHz were obtained at 429MHz. The antenna has an efficiency of 69% at this frequency.**

***Keywords*— CubeSat, Meander line antenna, CubeSat Antenna, Printed monopole antenna, Picosatellite.**

I. INTRODUCTION

Small satellite is classified into several types of satellites that are mini, micro, nano and pico satellites. Table 1 shows a comparison between these types such as mass, gain, cost and building time. The CubeSat is very small satellite belongs to the picosatellite class. A one unit (1U) CubeSat is the standard size of CubeSat with dimensions of 10cm×10cm×10cm and a wet no more than 1.33Kg[1]. The CubeSat operate in low earth orbit (LEO) and it is widely developed for various purposes such as communications, imaging and weather forecasting, military use such as spying and to provide secure communication link [2].

The communication system of CubeSat is very important part, as it ensures a connection to the ground station. Furthermore, the antenna should realize different functions such as telemetry, tracking and command (TTC), global positioning system (GPS), global navigation system (GNS), payload data and intersatellite cross links [3].

Table 1: Comparison between small satellite types.

Satellite Type	Cost ($)	Mass (Kg)	Building Time	Antenna Gain
Mini	10-50M	100-500	3 years	High
Micro	2-10M	10-100	1 year	Medium
Nano	0.2-2M	1-10	˜ 1 year	Medium
Pico	20-200K	1-1.3	< 1 year	Low

Several types of antennas are used in CubeSat such as monopoles, microstrip patch, helices and PIFA etc. depending on the frequency range, radiation and applications. Microstrip patch antennas do not satisfy the omnidirectional radiation required for TTC link. Wire antennas such as monopoles and dipoles are widely used as a CubeSat antennas as they are satisfy the omnidirectional radiation required for TTC link. These antennas are rolled around the satellite before deployment (Figure 1) [1, 4].

However, antennas that required mechanical deployment may increase the chance of mission failure if the antenna does not released out of the satellite. Several satellite missions were failed as a result of antenna deployment failed [5]. Designing an antenna operate in the UHF band that does not need mechanical deployment and fit to the Cubesat size and does not cover all the Cubesat face is a big challenges.

There are several techniques to reduce the antenna size such as: the use of substrate with high permittivity, slots in radiating patch, shorting pins and meander lines. To save space, the meandering-line configuration and folding techniques have been widely adopted by many researchers [6]. Meander line antenna is persuasive solution as it is a type of microstrip antenna and a transformation for monopole and dipole antennas [7].

By Meandering the patch the path of the flowing surface current will be increased and this will lowering the resonance frequency and make the antenna radiate at lower frequency than the wire antenna of same length.

The meander line antenna is a set of vertical and horizontal lines, combining the vertical and horizontal lines will form the turns. The property of a Meander line antenna is that if the number of turns increase the efficiency of the antenna will be increased and if the spacing between the turns increase the resonance frequency will be decreased [8].

In this paper, a printed meander line monopole antenna is represented to remove the need for deployment and to increase mission reliability. The antenna designed to fit the size of 1U and 2U Cubesat and cover less than a half of the Cubesat face which has dimensions of 80mm×50mm. The antenna is fabricated on FR-4 substrate with dielectric constant of ($\varepsilon r = 4.3$) and thickness of 1.6 mm. The antenna operates at the licensed lower UHF band 425 – 431 MHz.

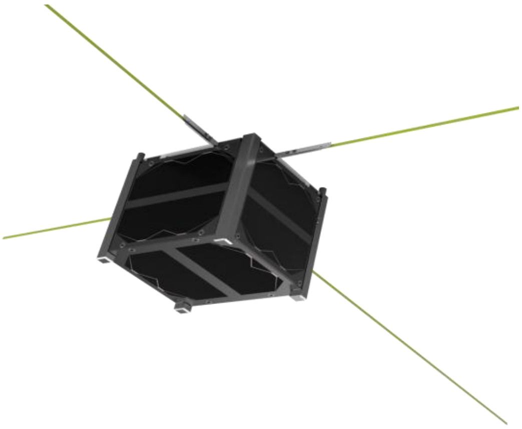

Figure1. 1U Cubesat with deployed antenna.

II. Design Requirements

It is very important to design an antenna that meets the requirements of the system. For CubesSat applications the following limitations and requirements should be considered in the design.

- According to NASA regulations, the dimensions can be selected as 1U CubeSat (10 x 10 x 10 cm^3), so the antenna should compact and fit the Cubesat size.
- CubeSat antenna must have wide coverage or omnidirectional radiation for TTC purposes.
- The antenna should not cover all the Cubesat face to provide additional space for the solar panels.

III. Frequency and Antenna Type Selection

The frequency should be one of the regulated VHF, UHF or S-Band allocated for CubeSat missions [9]. Based on the collected information and standards for the CubeSat deployed in orbit during the period 2000 - 2019, the analysis of these data lead to build the Figures (2) and (3). These Figures help us to select the frequency band and the antenna type as follows:

- According to Figure 2, most of the Cubesat antenna operates at the licensed lower UHF band (420 – 450 MHz).
- According to Figure 3, most of the Cubesat antenna uses dipole or monopole type.

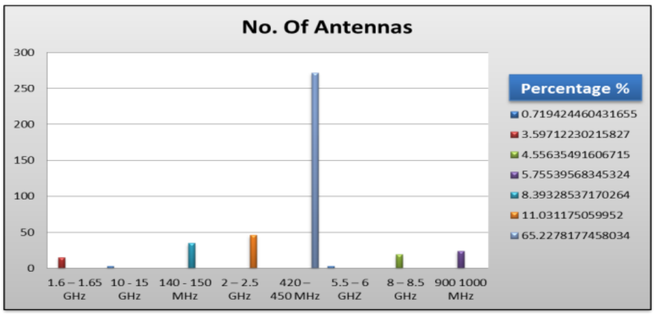

Figure 2. The most frequency band used in Cubesat.

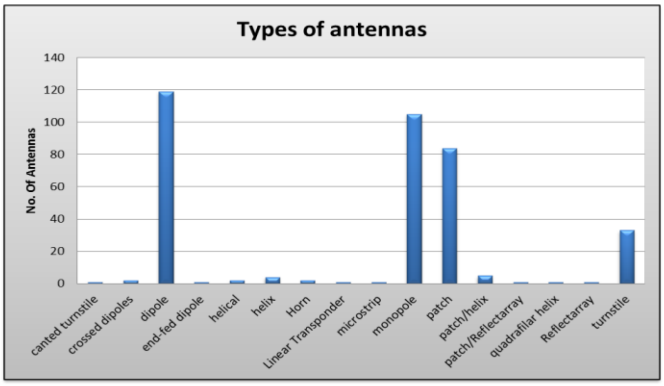

Figure 3. The most antenna type used for Cubesat.

I. REFERENCE ANTENNA CONFIGURATIONS

Printed mender line monopole antenna was used as a reference antenna as shown in Fig. 4. The reference antenna is designed using Computer Simulation Technology software (CST). Table 2 shows the values of the antenna dimensions.

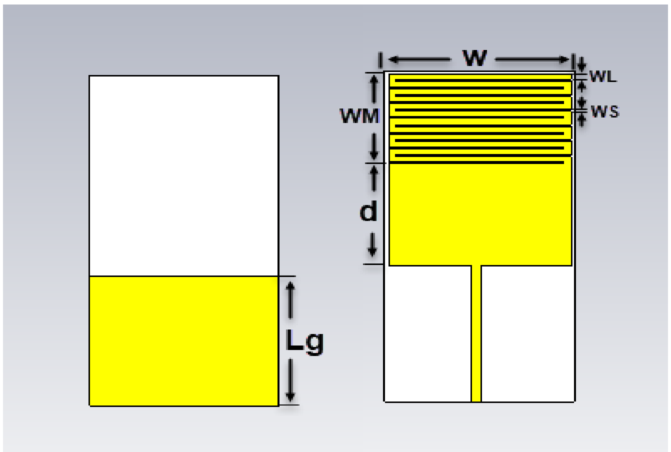

Figure 4. The Reference Antenna
(Front view and Back view)

TABLE 2: Dimensions of the reference antenna

Dimension	Value(mm)
W	52
WL	2
WS	0.5
WM	40
Lg	75
d	40

The reference antenna resonates at 431MHz with a band width of 10MHz and a return loss of S_{11}= -37dB as shown in Figure 5 [10]. From the above table it can be seen that the antenna width is appropriate for the CubeSat but the length of the antenna (WM+d+Lg = 40+40+75 = 155 mm) is too large and inappropriate for 1U CubeSat size.

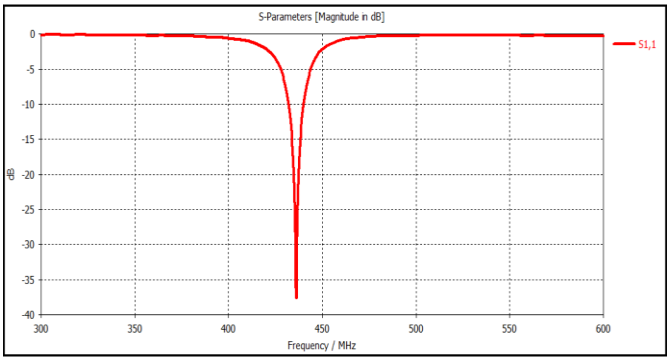

Figure 5. The return loss and operating frequency of the reference antenna.

In order to miniaturize the antenna size and lowering the lower edge frequency, some modifications have been executed on the reference antenna. The following steps describe the modified antenna after miniaturizing the antenna and making changes on it and how can these changes improve and affect the performance of the antenna.

II. Proposed Antenna Design

The modified meander-line antenna provides large size reduction by folding the conductor back and forth at the expense of narrow bandwidth. Meander-line antenna is a transformation of dipole antenna, it can be in a λ/2 dipole or λ/4 ground plane format.

The Antenna is printed on FR-4 substrate with dielectric constant (ε_r = 4.3) and loss tangent 0.019 as shown in Figure 6. The substrate has a thickness of h=1.6mm. The conductor thickness is set to 0.05mm above the substrate. The Antenna has a partial ground plane of a width Wa=50mm and a height of Lg=8mm.

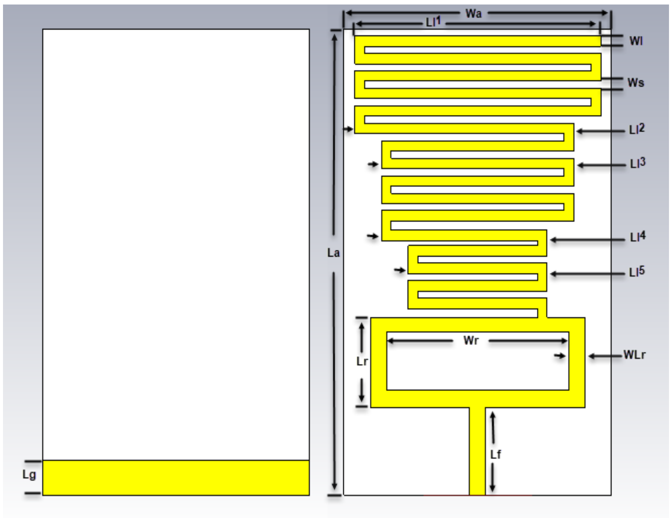

Figure 6. The proposed Antenna
(Front view and Back view)

The modified antenna consist of four parts the first three parts are different in length but all have the same width which is Wl. The fourth part is the rectangular shape shown in the bottom of the antenna and it is used for matching purposes. The width of the conductor in the rectangular shape is different from the width of the other three parts of the antenna and it is set to Wlr. The antenna is fed by a transmission line of a width 3mm and a length of 15mm.

A. *Parametric Study*

In order to achieve the best results several changes were made on the antenna line width and on the spacing between the lines. Table 3 shows the effect of changing the line width on the antenna results.

Table 3. Line width parametric study of the antenna.

Antenna line width(mm)	Resonant Freq.(MHz)	S11(dB)	VSWR	Gain(dB)
1.2	410	12	1.5	-0.83
1.5	424	15	1.3	0.17
1.8	429	17	1.2	0.32
2	447	11	1.4	0.091
2.2	461	12	1.4	-0.891

By decreasing the space between the lines the resonant frequency will be shifted to a higher frequency and vice versa. Table 4 shows the effect of changing the space between the lines on the antenna results.

Table 4. Space between the lines parametric study of the antenna.

Space between lines(mm)	Resonant Freq.(MHz)	S11(dB)	VSWR	Gain(dB)
1.2	442	9	1.3	-0.93
1.5	435	12	1.3	-0.96
1.8	429	17	1.2	0.32
2	421	15	1.3	0.15
2.2	414	16	1.4	0.14

As shown from Figure 6, the antenna size fit to the CubeSat size and cover less than a half of the CubeSat face.

Table 5 shows the values of the optimized antenna dimensions.

TABLE 5: Dimensions of the proposed antenna

Dimension	Value(mm)
La	80
Wa	50
Lg	8
Ll1	46
Ll2	41
Ll3	36
Ll4	31
Ll5	26
Wl	1.8
Ws	1.8
Wlr	3
Wr	40
Lr	15
Lf	15

B. *Simulation Results*

The resonant frequency of a meander line antenna can be achieved by either by increasing the line width of a meander line antenna which generates the capacitance to the ground plane or by increasing the meander lines number which generates inductance for frequency adjustment.

All the above parameters have been optimized by tuning the line width, the line length and the spacing between the lines to have the optimum size reduction for the antenna to be appropriate for the CubeSat size. As shown in Figure 7, the antenna achieved -17.2 dB return loss and VSWR of 1.2 and operates at the lower UHF band of 429 MHz.

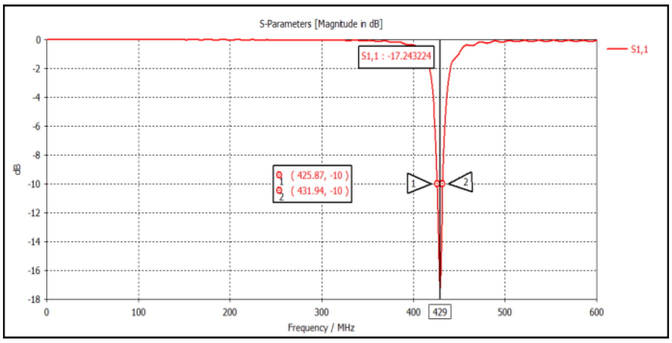

Figure 7. Simulated return loss and operating frequency of the proposed antenna.

The simulated bandwidth is 6 MHz and the achieved gain is 0.32 dB which are suitable for the application of TTC of CubeSat. The omnidirectional radiation pattern required for TTC of CubeSat is achieved at 429 MHz with 69% radiation efficiency as shown in Figure 8 & 9.

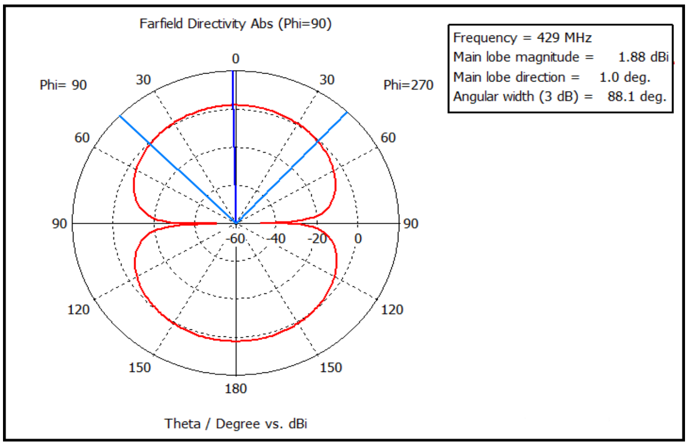

Figure 8. Simulated 2D radiation pattern.

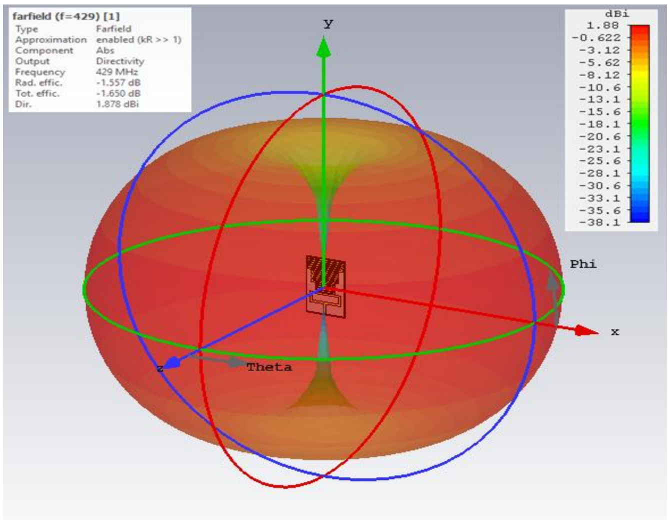

Figure 9. Simulated 3D radiation pattern.

As mentioned previously, the wide coverage radiation is very important during the launching phase, to ensure that the CubeSat does not lost in space. Figure 10 shows the simulated radiation efficiency and Figure 11 shows the surface current distribution of the antenna in A/m.

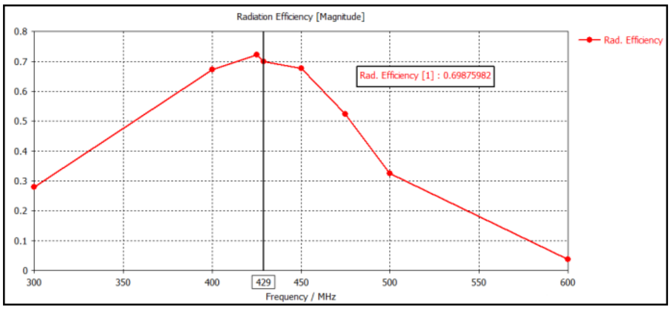

Figure 10. Simulated radiation efficiency

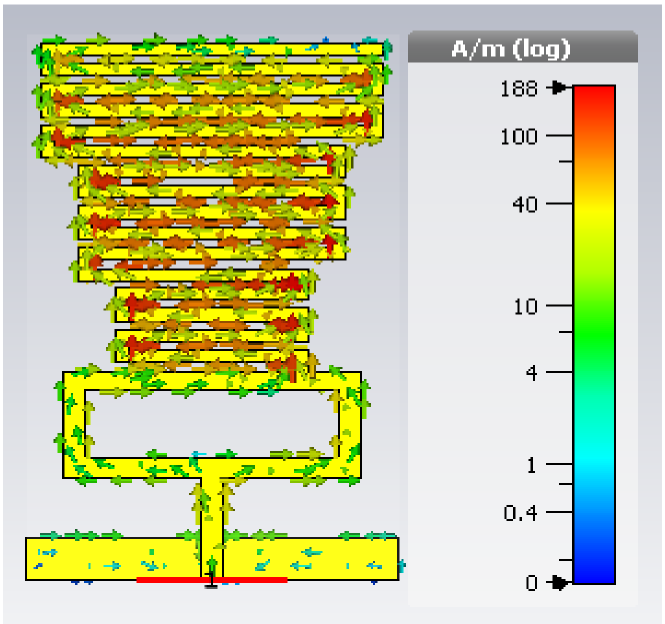

Figure 11. Surface Current distribution of the proposed antenna.

III. PRACTICAL IMPLEMENTATION

The proposed mender-line monopole antenna was practically implemented. The mechanical structure of the CubeSat also has been manufactured for testing the performance of the antenna with and without the CubeSat structure.

Figure 12 shows the front and back sides of the fabricated antenna. The dimensions of the fabricated antenna are the same as in table 3. The fabricated antenna was tested on vector network analyser having a range from 300 MHz to 600 MHz.

Figure 12. Practical implementation of the proposed antenna.

A. *Antenna Performance without the CubeSat*

Figure 13 shows the return loss of the fabricated antenna without the CubeSat. It can be seen from the figure that the fabricated antenna resonates at lesser frequency than the simulated design. The fabricated antenna radiates at 425 MHz which is in the range of the licensed band (420-460 MHZ). The value of S11 is -11 dB at 425 MHz. The measured band width is 10 MHz at -10 dB which is greater than the simulated band width and suitable for the application of TTC of CubeSat.

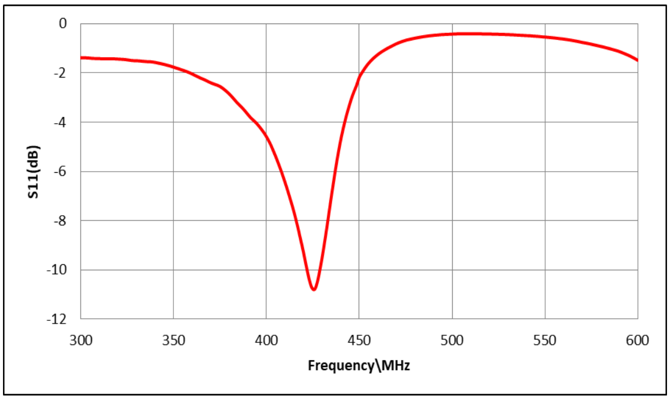

Figure 13. Return loss of the fabricated antenna.

A VSWR of 1.4 is recorded at 425 MHz for the fabricated antenna which is also in the acceptable range. The smith chart shows impedance value of 45.3Ω at 425 MHz which is close to the characteristic impedance of 50Ω as shown in Figure 14.

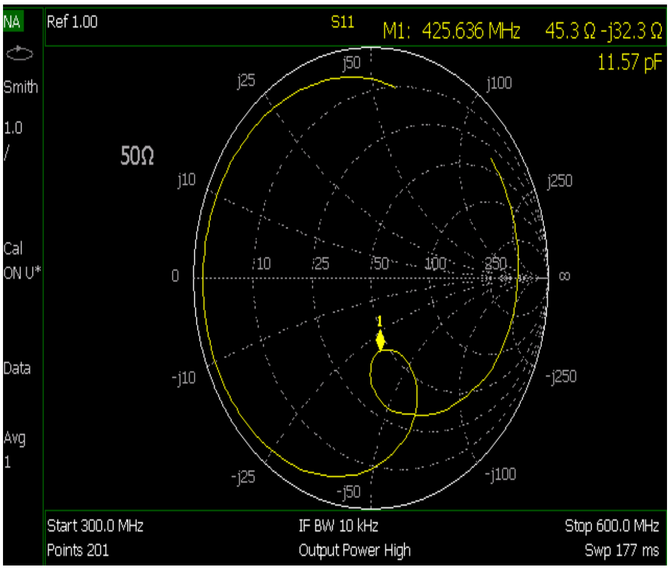

Figure 14. Smith chart of the fabricated antenna.

B. *Antenna Performance with the CubeSat*

The Antenna performance was tested on 1U and 2U CubeSat as shown in Figure 15 and Figure 16. The CubeSat consists of Aluminum frame covered by the solar panels and FR-4 tablet located between the Aluminum frame and the solar panels. So the antenna is isolated by the FR-4 from the Aluminum frame of the CubeSat.

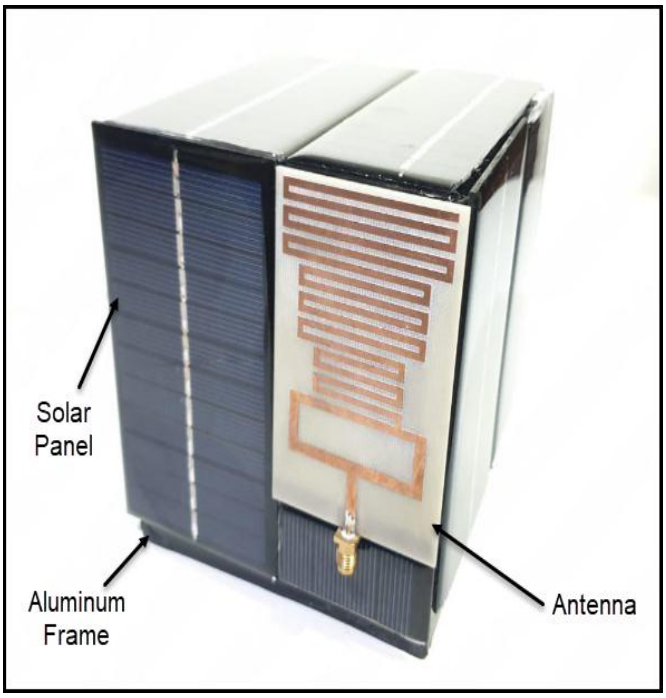

Figure 15. The proposed antenna with 1U CubeSat.

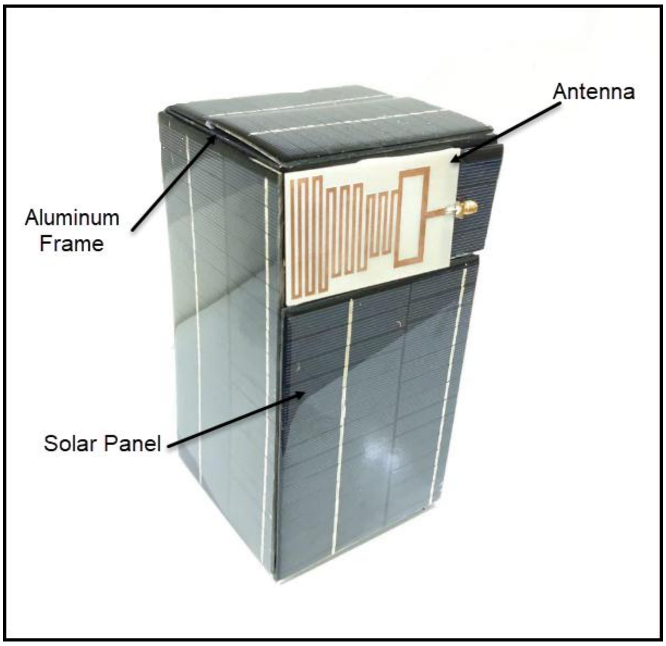

Figure 16. The proposed antenna with 2U CubeSat.

The return loss of the antenna is -13 dB at 423 MHz when the antenna located on the CubeSat, That's mean the antenna resonate at lower frequency when located on the CubeSat as shown in Figure 17. The band width is increased to 12 MHz compared to the bandwidth of the antenna without the CubeSat.

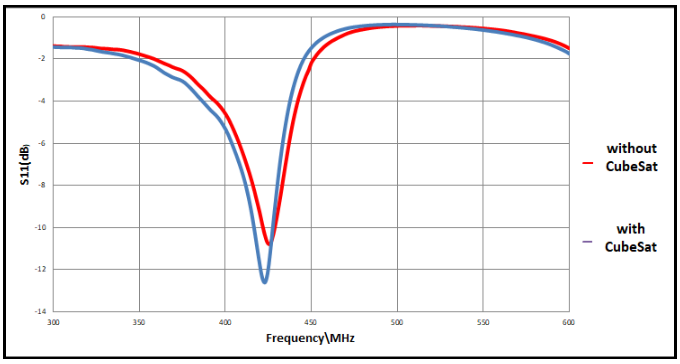

Figure 17. The return loss of the antenna with and without the CubeSat.

From the collected measurements of the fabricated antenna, the results of the fabricated antenna are all in the acceptable ranges and suitable for real-time applications of TTC of CubeSat. Table 6 shows a comparison between the simulated results and fabricate d results.

Table 6. Comparison between simulated and measured results.

Parameters	Simulated Result	Measured Result (Without CubeSat)	Measured Result (With CubeSat)
S11 (dB)	-17	-11	-13
Bandwidth (MHz)	6	10	12
VSWR	1.2	1.4	1.6

V. COMPARISON WITH OTHER WORKS

In the case of antenna deployment, the CuneSat engineers have to take into account the complexities for the design of deployment mechanism as in [11]. The proposed antenna provides deployment-free operation to improve mission reliability and to allow the engineers to focus on other criteria. From the obtained results it can be seen that the proposed antenna have a compact size which is suitable for 1U and 2U CubeSat. The bandwidth and gain of the antenna are in the acceptable range for the CubeSat applications. Table 7 provides a comparison for the proposed antenna with other works.

Table 7. Comparison for the proposed antenna with other works.

REF. NO.	ANTENNA TYPE AND SIZE (mm)	FREQUENCY (MHZ)	COMPATIBILITY OF CUBESAT
Reference antenna[10]	Meander line monopole(155×52)	426-436	Too large and not compatible with 1U CubeSat
[11]	Dipole (160)	430	Compatible with CubeSat but need deployment mechanism
[12]	Microstrip patch (170×120×6.4)	435-437	Too large and not compatible with 1U CubeSat
[13]	Fractal-shaped (120×120×1.6)	470-700	Not compact enough. Does not cover the licensed lower UHF band (420-460 MHZ)
[14]	Microstrip patch (150×150×37)	384-410	large and not compatible with 1U CubeSat
[15]	Monopole (175)	435-438	Compatible with CubeSat but Deployable complexity
[16]	Printed patch (320 × 80 × 3.17)	427–437	Too large and not compatible with 1U,2U CubeSat
[17]	InvertedF Antenna	398 –405	Compatible with 1U CubeSate but have design complexity
Proposed Antenna	Printed Meander line (80 × 50 × 1.7)	425-431	Compatible with 1U and 2U CubeSat and free from deployment complexity

VI. CONCLUSION

The proposed antenna has a compact size of (80 × 50 x 1.6) which is suitable for the CubeSat size and cover less than a half of the CubeSat face. The antenna is free of the deployment mechanism. The design has been simulated using CST software; also the design has been practically implemented and measured with and without the CubeSat structure. The results of the designed antenna such as S11>-11, Gain=0.32, VSWR=1.2, Bandwidth=6MHz and Efficiency=67% are all acceptable. The fabrication results have a good correspondence with the simulation results.

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