Design and Optimal Placement of Deployable Dipole Antennas for Micro and Nano Satellites

Yumna Gillani, Iqra Saeed, Moazam Maqsood, Rehan Mahmood and Tariq Mehmood

***Abstract*— This paper presents the optimum design configuration for a pair of deployable dipole antennas for Pakistan National Student Satellite (PNSS-1) which is a 50 kg, 3-axis stabilized satellite targeted for imaging applications. The proposed antenna configuration consists of a pair of dipoles mounted on a 50 cm x 50 cm satellite body and they operate at 435 MHz and 146 MHz. The objective of this study is to maintain a return loss of -10 dB or below and simultaneously ensuring that the gain does not fall below a lower bound because that would be insufficient for the communication data rate of 9600 bps. By varying the antenna placement and orientation on the satellite body, these requirements were achieved. Simulated results show that despite different gain patterns the return loss remains below -10 dB.**

***Index Terms*— Deployable antennas, dipole antennas, microsatellites, radiation pattern**

I. Introduction

THE advancement in satellite communication systems has encouraged many researchers to participate in the satellite payload development and demonstration [1]. Many universities and R&D organizations around the world are integrating and launching their own micro/nano satellites by making use of off the shelf components (COTS) [2],[3] enabling significant cost reductions for satellite industries. This has given the students an opportunity to work in a professional environment for building these small satellites that can be used for different applications such as telecommunications, Earth observation, space science, mitigation and management of disasters (floods, fire, earthquake, etc.), military applications, education, training and in-orbit technology verification [4].

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Pakistan National Student Satellite (PNSS) is also one such venture that encouraged different universities across Pakistan to collaborate and come up with satellite subsystems for given requirements.

Since these satellites use amateur bands (VHF/UHF) to communicate with the ground station[3], they require large antennas to be placed on the satellite. This is difficult, in particular for CubeSats, as they are unable accommodate large antennas in a very small size. Deployable antennas are used in small satellites to overcome this issue as these require a smaller area in the stowed configuration[5][6].

Different types of antennas have been proposed for the CubeSat. Some comparisons have been made between monopole and dipole antennas. Monopoles are quite advantageous due to their less weight and smaller length than dipole antennas. Also, its deployment is easier and it occupies less space for its mounting. But the problem with monopole antenna is that it produces a minimum signal in the axis of the antenna while the dipole antenna produces two element geometry which attenuates the minimum signal [7]. Furthermore, dipole antennas are omnidirectional and easy to design. The radiation pattern of double monopole antenna (dipole) with significant peaks and nulls can help in overcoming the undesirable communication blackouts[4].

Hence, one suitable choice for the Cubesat is dipole antenna due to its stable radiation pattern without requiring a larger ground plane [8].

In space atmosphere the antennas need to operate with high reliability. They must be mechanically robust and strong enough to survive the launch while having the capability to withstand certain harsh radiations including ionizing radiation in the space environment[4]. They should be able to operate in a wide temperature varying from -150° C to +150°C. Despite these common requirements, different satellites require different antennas due to their radiation pattern and other performance parameters.

In Polysat, a CubeSat developed by students of California Polytechnic [9] the antennas are wrapped around the satellite before deployment, and are held in place with the help of monofilament and a short length of Nichrome wire inside the satellite. The moment a current is passed through this Nichrome wire, the monofilament heats up ending up releasing the antennas.

According to the requirements specified by Pakistan National Student Satellite Program, three dipoles need to be developed. The deployable receive antenna (DRA) shall operate in VHF band at a frequency of 146MHz. There should be two deployable transmit antennas (DTA), one for Telemetry, tracking, and command and other for Payload. Both antennas shall operate in UHF band at a frequency of 435MHz. All three antennas should have linear polarization and their gain should be maximum towards the Nadir direction. Enough separation is needed between the antennas in order to keep the space available for the camera payload which is discussed in the section IV.

This paper presents the design of a deployable dipole antenna for a small satellite. Similar to delfiC3 satellite[10], a modular antenna box with an antenna is placed in stowed position inside. A Dyneema wire keeps the lid of the box closed from one end and is wound to a resistor on the other end. As the resistor is heated up, the Dyneema wire burns thereby opening up the lid and strip tape antenna is deployed. The antennas are placed independently at the plate edges. In order to combine them as dipole pairs 180° hybrid couplers are used.

Four design configurations with different antenna placement mounted on 50 cm x 50 cm base plate which have been simulated and analyzed for radiation pattern uniformity and maxima direction. The first three models, use two dipoles pairs each while the fourth model converts the best configuration of two dipole models to accommodate a third pair. The antennas have been simulated using CST [11]while the hybrid couplers have been designed using Agilent ADS [12].

II. Antenna Designs

A small microcontroller [13], installed on a small PCB, is used to enable the current flow which burns the resistor, allowing the antenna to get deployed. The same PCB also provides the ground plate for individual dipole element and a termination mechanism for RF connector.

The deployment mechanism circuit, shown in Fig. 1, consists of a PIC16F88 microcontroller, a 2N3904 transistor which is supplied a V_{cc} of 28 V and an operational amplifier LM741 acting as a comparator. The antenna have been developed using flexible measuring tape rolled and stowed in an acrylic box. A Dyneema wire was attached to the lid of the box. It is also wound across the collector resistor. The microcontroller receives a signal from OBC of the satellite which turns on the Microcontroller and hence BJT transistor. The resistor connected to the collector of the BJT gets burned as soon as the BJT is turned on, releasing the Dyneema wire wound around it. As a result, the lid of the modular box is released resulting in the deployment of the antenna. Moreover, to notify whether the antenna has been deployed or not, the BJT collector output is fed to a comparator with a reference voltage of 5 volts. When the BJT is in off state, the output from the collector of the BJT gives a voltage almost equal to V_{cc} supplied to it and LED remains off.

The modular antenna box has overall dimensions of 10 cm x 10 cm x 2 cm. The prototype and PCB is shown in Fig. 2 and Fig. 3 respectively while the 180° hybrid is shown in Fig. 4. The hybrid is actually a meandered rat race coupler[14] fabricated using RO6006 (ε_r=6.6, h = 1.6 mm)[15].

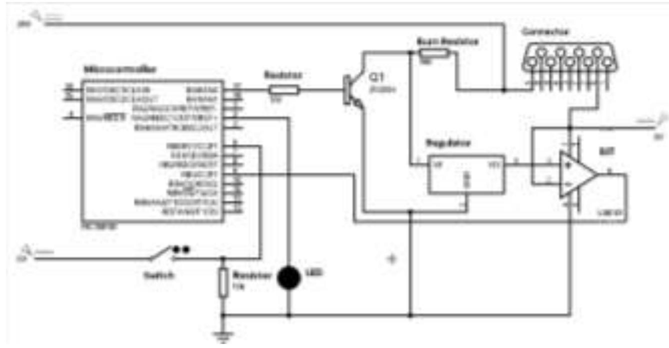

Fig 1. Deployable Mechanism Circuit

It has an overall size of 6 cm x 6 cm. 180° coupler is required to provide differential current in the two monopole elements, combining them to behave as a single dipole. The overall polarization of antenna remains linear (horizontal).

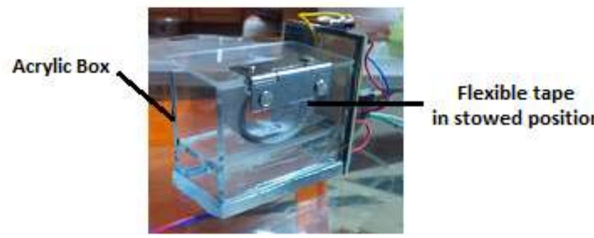

Fig 2. Front side of deployable antenna prototype

Fig 3. Back side of deployable antenna prototype

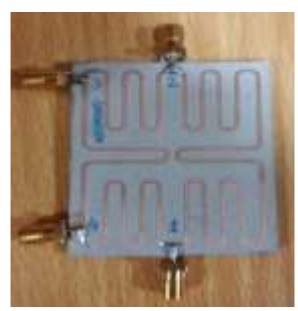

Fig 4. Rate-Race hybrid coupler

III. Antenna Models

Four antenna models are shown. The antenna elements are modeled using 1 mm radius wire.

A. First model:

Fig. 5 shows the antenna model with all four antenna boxes placed at four edges of the base plate. Fig. 6, 7 and 8 show the simulated results of the antenna. It can be seen that although there exists a pattern maximum at VHF band towards Nadir direction, a null exists for UHF band suggesting that the antenna may not work at both frequencies.

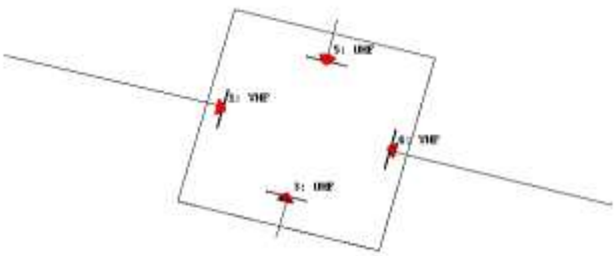

Fig 5. First design configuration with four monopoles mounted at the center of each side of the satellite surface

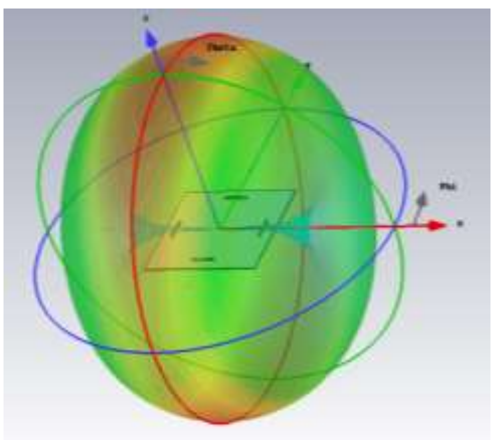

Fig 6. Radiation pattern of UHF poles at 435 MHz

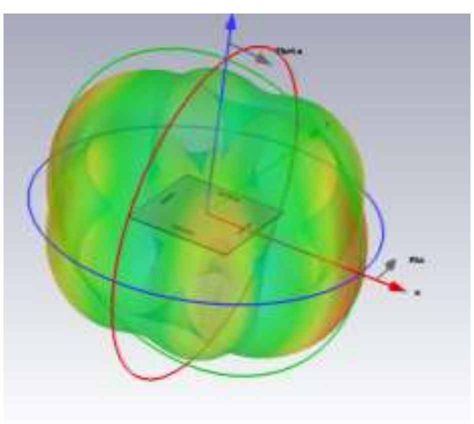

Fig 7. Radiation pattern of VHF poles at 146 MHz

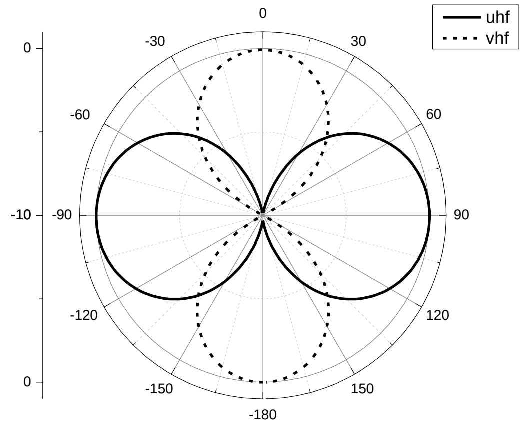

Fig 8. Gain plot at the elevation angles varying from 30 to 180 degrees

B. Second model:

Fig. 9 shows the second model. Fig. 10, 11 and 12 show the simulated results of the antenna. Again, it can be seen that the VHF antenna has a gain maximum towards Nadir but the UHF pattern is directed towards one side. This non-uniformity in the pattern can be attributed towards the non-symmetric nature of the antenna placement.

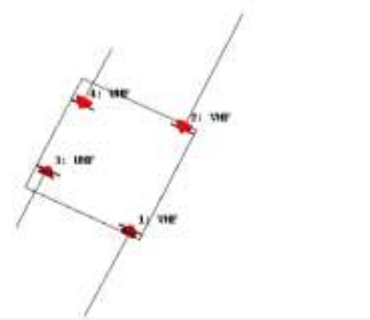

Fig 9. Second design configuration with four monopoles mounted at the corner of each side of the satellite surface

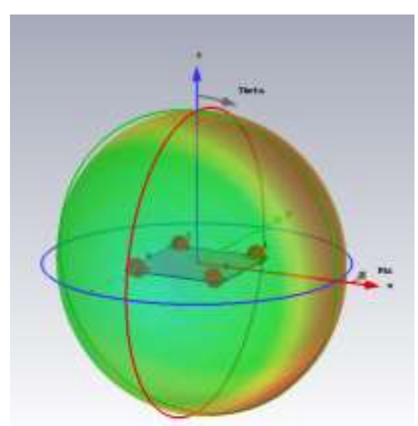

Fig 10. Radiation pattern of UHF poles at 435 MHz

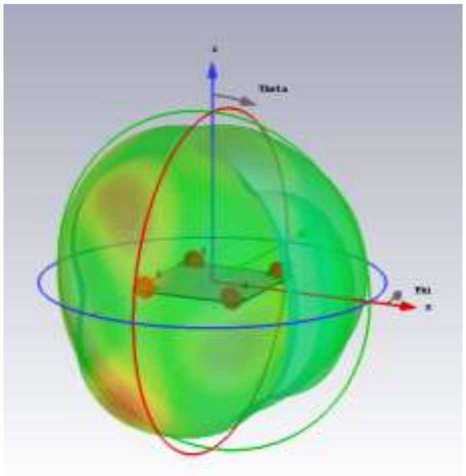

Fig 11. Radiation pattern of VHF poles at 146 MHz

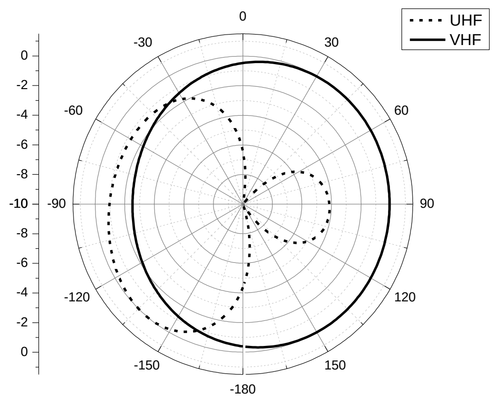

Fig 12. Gain plot at the elevation angles varying from 30 to 180 degrees

C. Third model:

Fig. 13 shows the third model. This configuration is unique in a way that usually progressive installation is used for monopoles belonging to the same frequency but here two different lengths have been used in the progressive fashion. Simulated radiation patterns shown in Fig. 14, 15, and 16 show that the antenna radiates maximum towards Nadir for both VHF and UHF bands. This may be surprising as each dipole pair has a diagonal spacing but since the wavelength is large the spacing seems irrelevant.

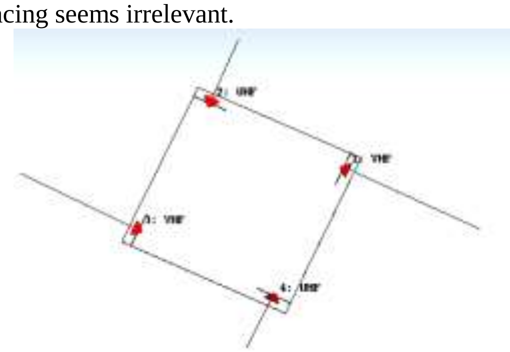

Fig 13. Third design configuration with four monopoles mounted at the corner of each side of the satellite surface

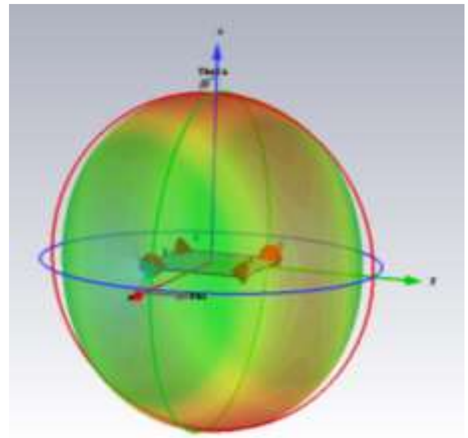

Fig 14. Radiation pattern of VHF poles at 435 MHz

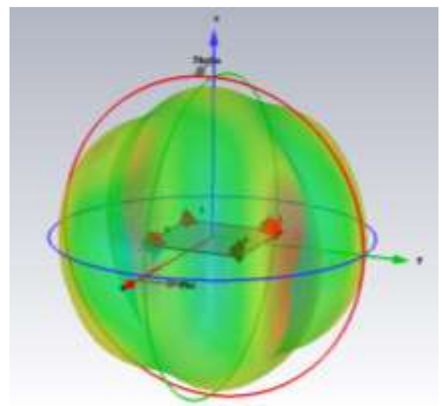

Fig 15. Radiation pattern of UHF poles at 146 MHz

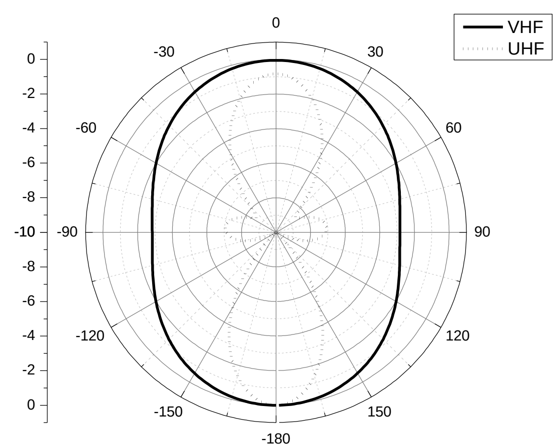

Fig 16. Gain plot at the elevation angles varying from 30 to 180 degrees

D. Fourth model:

The fourth and last model is a hybrid of first and second models and is preferred over progressive placement due to ease of placement and better symmetry. The first model is used for VHF as it was operating with maximum directivity towards Nadir while second model has been modified to allow symmetric configuration for UHF antennas thereby eliminating the pattern deformity allowing the antenna to have maximum radiation towards Nadir direction. Fig. 17 shows the antenna model while Fig. 18, 19, 20 and 21 show the results. It can be seen from Fig. 21 that UHF1 and UHF2 antennas have a very small beamwidth i.e. approximately 20° but this may not be a problem for the continuity of the communication link as PNSS is a 3-axis stabilized satellite and will therefore provide enough pointing accuracy.

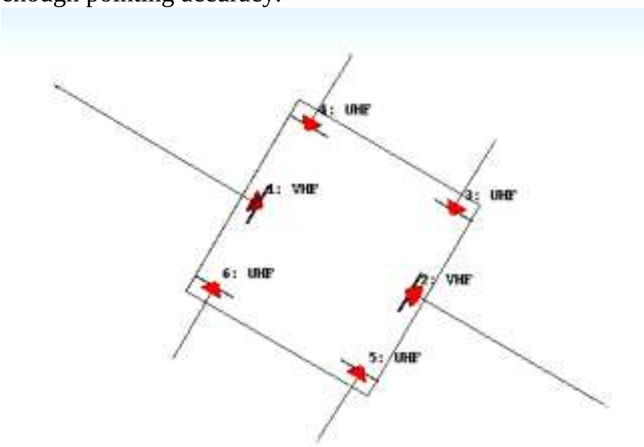

Fig 17. Fourth design configuration with four monopoles at 435 MHz and two monopoles at 146 MHz

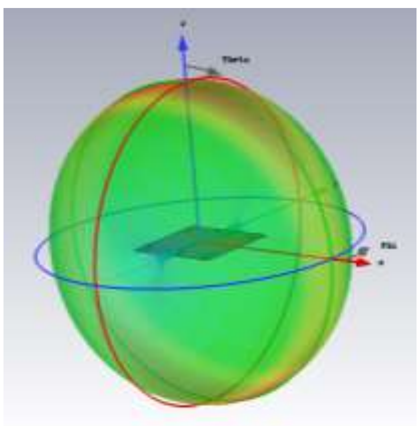

Fig 18. Radiation pattern of VHF poles at 435 MHz

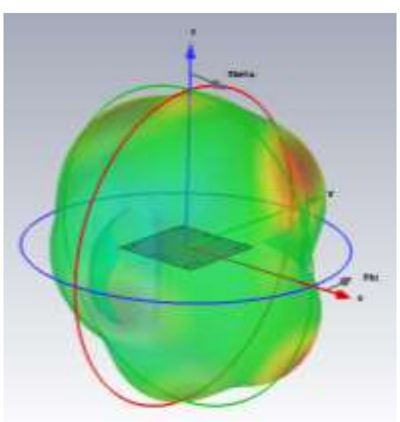

Fig 19. Radiation pattern of UHF 1 poles at 435 MHz

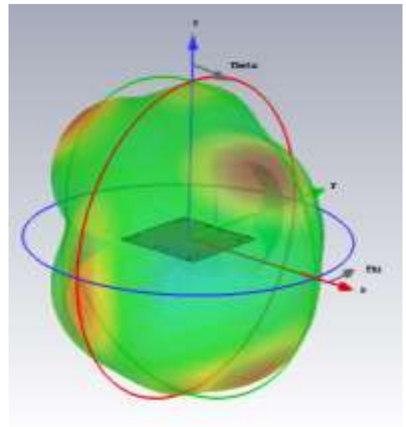

Fig 20. Radiation pattern of UHF 2 poles at 435 MHz

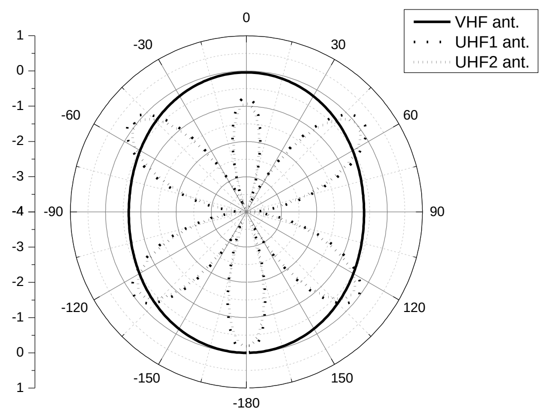

Fig 21. Gain plot at the elevation angles varying from 30 to 180 degrees

IV. Conclusion

In this research, design configurations of deployable dipole antennas for Pakistan National Student Satellite (PNSS-1) are presented. It can be observed that through the change in antenna placement and orientation on the satellite body, the radiation patterns are affected. Among all the four designs, the fourth design is observed to be the most suitable one with the dipole antenna placement orthogonal to each other giving linear polarization. In this design, two parallel antennas operate at UHF and the other parallel pair operates at VHF. Discussed simulation results show the suitability of the proposed configuration for future satellite applications. In this paper, the prototype is discussed but for future work consideration, the model has to use space grade components which comply with the atmospheric conditions of space.

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