Design, Analysis and Testing of Monopole Antenna Deployment Mechanism for BIRDS-2 CubeSat Applications

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Abstract This paper presents an approach to design a feasible and reliable monopole antennae deployment mechanism for CubeSat applications. Nano-satellite has faced problems in designing antennae deployment system due to space and deployment mechanism constraints. In BIRDS-2 CubeSat, the nichrome wire burning release mechanism was used when activated, it will be heated up and thermally cut through fishing line, allowing the two monopole antennas to be deployed on +Y board and at +Z axis direction of the satellite. These antennae involved amateur radio frequencies in UHF and VHF bands due to its low cost and high accessibility by the end users. The UHF frequency band was used for command uplink, mission, telemetry, and CW beacon downlink whilst the VHF frequency band was used specifically for APRS-DP/S&F-RDC mission for both uplink and downlink. In order to achieve the effectiveness of the BIRDS-2 CubeSat communication system agreed with the link budget estimation, the dimensions of antennae on the CubeSat structure depend on the required gain and operating frequency. The paper discusses detailed results of mechanical and electrical interfaces of the two monopole antennas deployment mechanism with the satellite body and the nichrome wire burning release mechanism analysis. The tests results of the mechanism were analyzed particularly on the deployment time and the nichrome wire temperature differences.

1. Introduction
The antenna is an essential part of a nano-satellite. It facilitates communication between the nano-satellite and the ground station. A majority of the nano-satellites launched so far are intended to operate in the amateur VHF (144-146 MHz) and UHF (435-440 MHz) frequency band [1], so as in BIRDS-2 CubeSat. Regardless all the challenges in the 1U dimension limitation, both antennae designs should be implement miniaturization and envelope techniques of deployment mechanism to comply with the constraint. The development of BIRDS-2 antennae deployment mechanism is categorized into Antenna Securing (Stowage) and Antenna Deployment. Antenna deployment subsystem mechanism elements for BIRDS-2 CubeSat are discussed in more detail in the following sections.

2. Mechanism Elements
The mechanism depends on the main part called the secure part, which is a 3D printing material (white plastic) where antennae will be attached to. These are the elements needed for the mechanism’s operation which is located at the external configuration of +Y board which includes the secure parts (3D
printing material), antennae retention fishing line (dedicated mounting screws) and an antennae deployment detection switch. Figure 1 shows the deployment mechanism’s location at the external configuration of +Y board. The burner circuit will be placed at the internal configuration of +Y board as in Figure 2 where the nichrome wire will be penetrated through a dedicated hole and appears at the external configuration of +Y board. The operation of the burner circuit mechanism is very simple.

The retention fishing lines allow antennae to be secured, retained and keep antennae folded until the time for deployment. At that moment BIRDS-2 CubeSat unregulated power supply is turned on the burner circuit be activated and finally heat up the nichrome wire, cut the fishing line, and therefore deploying antennae, as shown in Figure 3.

2.1. Monopole Antennae Characteristics
The monopole antenna for UHF and VHF frequency band were chosen due to its ease of deployment, omnidirectional radiation pattern and higher gain to establish communication according to link budget analysis. Both UHF and VHF monopole antennae will be folded during the journey to the space and deployed once the satellite is in orbit. The mounting screw has enough force to keep both antennae folded and tied (triple knots) by the retention of a fishing line (Polyethylene (PE)), which will keep it secure. Both monopole antennae have the same width of 4mm and thickness of 0.3mm; with different length according to quarter wavelength calculations. UHF monopole antenna length is 175mm whilst VHF monopole antenna have a length of 501mm. Monopole antennae
are driven using a discrete source with the conducting BIRDS-2 CubeSat body, which acting as the ground plane for both antennae. The proposed material for both monopole antennae is carbon tool steels, SK85 (SK5) [2].

2.2. Retention System
The element used for the retention of the antennae for securing purpose is polyethylene (PE) material, known as fishing line. This type of fishing line can endure a maximum weight of 37kg and unlikely to have a failure of the retention system due to yielding of fishing line. Antennae were initially in the secured position and held at the dedicated mounting screws by using fishing line. In this mechanism, the free end of each antenna was tied with a single fishing line and after securing them in proper tensile [3], it was passed over the nichrome wire coils and fixed to the two dedicated mounting screws as a final point. These mounting screws were provided for the nichrome wire in order to hold the retention of the fishing line while the nichrome wire as in tension in the secured position of antennae. This support not only provides the means to fix the nichrome wire too but also provides a path for the fishing line. The retention of fishing line passes over the nichrome wire in a straight formation so that there will be maximum contact area between the nichrome wire and the fishing line and effective heat can be transferred between them. The current was passed through the nichrome wire and as a result, the nichrome wire heats up which in turn leads to the melting of the fishing line.

2.3. Burning Mechanism
The nichrome burn wire release mechanism uses a nichrome burn wire which when activated, it will be heated up and thermally cut through fishing line, allowing both deployable antennae on the satellite to actuate. The entire burner circuit mechanism will remain inside of except for the nichrome wire which will be outside the satellite. The burner circuit is powered with unregulated supply from EPS and 3.3V signal from (Attitude Determination and Control System) ADCS microcontroller. After 30 minutes releasing from ISS, the EPS turn on the unregulated power. ADCS Microcontroller will detect power of unregulated power line and start send the 3.3V signal to the burner circuit, thereafter heat up the nichrome wire, release the fishing line and deploy both monopole antennae. Both monopole antennae will be deployed on +Y panel and at +Z axis direction of the satellite.

2.3.1. Nichrome wire. The nichrome wire resistance value is depending on the length of the nichrome wire itself. In order to select the correct nichrome wire from those available commercially, many room temperature tests were conducted by using different types of nichrome wire until the suitable length are determined. After rigorous tests, for an input voltage of 3.7V which is the voltage commonly provided by the batteries used in CubeSats, it was decided that the length of the nichrome wire is 10.5cm with a resistance value of 8.2Ω was the best and suitable for the deployment mechanism. The deciding parameters comprised of maximum temperature reached by the nichrome wire, burning time of the fishing line and compatibility with the Overcurrent Protection circuit (OCPC) located at Electrical Power System (EPS) board which limits the current of the maximum of 2.77A.

2.3.2. Burner Circuit Board. The burner circuit consists of a high side Metal Oxide Semiconductor Field Effect Transistor (MOSFET) switch which is designed to protect loads from damage due to a latch up. It can also be used as a controllable switch (signal 3.3V) by the Attitude Control and Determination System (ADCS) Micro Controller Unit (MCU) of the CubeSat to switch off loads in case of an emergency or in the case of the Power Management Algorithm of the CubeSat demands it. The algorithm for the antennae deployment will be programmed in ADCS MCU, depending on parameters of nichrome wire burning time and maximum temperature required to burn up the nichrome wire.

2.3.3. Power Supply from Batteries. After the length of the nichrome wire and its resistance value were determined and the position of antennae was fixed, more than 30 tests were conducted to estimate the required time for deployment. All tests were conducted by using BIRDS-2 batteries which at the worst
condition (less than 10% charging capacity). As room temperature tests continued, batteries capacity and supply voltage were monitored. From the results of these tests we detected and observed that the nichrome wire, when subjected to lower voltages than the nominal ones (3.7V), underwent deterioration and a slight variation in their properties when the current was passed through them. This was helpful when determining the point at which the nichrome wire was capable of burning the fishing line in a much colder environment in space and not destroy itself at room temperature. For this, the deterioration was related to the variation in the current flow by maintaining the voltage constant over time. This fact can only be due to the variation in the nichrome wire resistance value over time due to the deterioration through overload. A test is conducted to observe the time taken for antenna deployment by increasing the current supply gradually in order to determine the suitable current supply value. The average value was found to be 4.56 seconds for deployment using 2.75A of current supply. To ensure deployment, the burning time was set to the maximum of 10 seconds and maximum temperature was set to 213˚C in the ADCS MCU algorithm with the function to control and activate antennae deployment within its time. This is important in order to prevent batteries from draining out if the nichrome wire continuously keeps burning.

2.3.4. Temperature Sensor. The nichrome wire coils around the retention wire and functions with the help of a burner circuit that is designed to be switched on for a calculated period of time so as to allow current to pass through it and the temperature sensor would correspond to the temperature reached by the nichrome and when the temperature is slightly above the melting point of fishing line, its resistance would be a definite value and the current would provide a definite voltage across it. This circuit has a feedback system that uses temperature sensor which would let the ADCS MCU knows when the temperature reached the optimum level.

3. Monopole Antennae Measurement
The electrical characteristics of an antenna that are of interest to obtain by direct measurement can be categorized into 3 measurements:

3.1. Reflection Coefficient Measurement (Frequency Tuning)
Both UHF/VHF antennae will be connect to Port 1 of calibrated Vector Network Analyzer to be tuned at the desired resonance frequency and $S_{11}$ parameter will be measured. This test was done iteratively by trimming the antenna length till a resonance at the frequency operation for UHF Downlink/Uplink and VHF were obtained [4]. The measurement setup will consider the horizontal and vertical orientation for both UHF/VHF and also for the transmit antenna, in the condition of both antennae is not deploy and deploy. The optimum $S_{11}$ parameter measurement results for both UHF/VHF antennae are as shown in in Table 1. As per the reflection coefficient measurement, for the intended resonance frequency operation for both UHF (downlink and uplink) and VHF, the antenna length of 175mm (for UHF) and 501mm (for VHF) provided the maximum efficiency. The efficiency of the UHF Downlink antenna is 0.08962dB, or 91.04% while for UHF Uplink antenna is 0.0836dB, or 91.64%. Both -10dB bandwidth is 28MHz. The $S_{11}$ characteristics of the VHF monopole antenna shows the efficiency of 0.08974dB, or 91.03%. By referring to above-mentioned efficiency of UHF/VHF antennae, about 9% of the incident power are reflected by antennae and roughly, about 91% of the available power is transmitted into antennae.

3.2. Gain measurement
The technique used to conduct the monopole antennae measurement is by using gain comparison method; using two antennae with reference using 3 antennae. According to the link budget calculation,
the estimation gain of the UHF/VHF monopole antennae should be in the margin of 0 – 2.2 dBi and the
desired radiation pattern should be omni-directional pattern. The result of gain of both UHF/VHF
antennae calculated is shown as in Table 2. By referring to the gain result in Table 2, all the calculated
gain meet the link budget estimation, thus can establish good communication and perform missions
successfully from ground station to BIRDS-2 CubeSat and vice versa.

| Type of Antenna | Condition of Antenna | Frequency (MHz) | AUT Gain (dBi) |
|-----------------|----------------------|-----------------|---------------|
| UHF Downlink    | Deploy/Not Deploy    | 437             | 4.45/5.15     |
| UHF Uplink      | Deploy/Not Deploy    | 435             | 6.59/5.39     |
| VHF             | Deploy/Not Deploy    | 145             | 7.57/4.27     |

### 3.3. Antennae Radiation Pattern Measurement Results

The optimum results of radiation pattern is when antennae are both in deployed condition, transmit
antenna is in horizontal position and satellite in a vertical position (+Y panel is facing the transmit
antenna). From the results of radiation pattern with these conditions, it shows that the monopole
antennae perform omni-directional patterns. The 2-D polar plot results are as presented in Figure 4
(a), (b) and (c). The peak directivity in the azimuthal plane (constant θ = 90°) for UHF Downlink antenna
is 4.45dBi while for UHF Uplink antenna is 6.59dBi. Both peaks directivity are highest at the angle of
240° position. From the 2-D polar plot for VHF antenna in Figure 4(c), it can be seen that the VHF
antenna has a distorted radiation pattern within the angle of 120° to 180°, and 300° to 330°, with slightly
higher directivity which is 7.57dBi at 240° angle position. Besides of the satellite orientation during the
radiation pattern measurement, the presence of the metal structure has a significant effect on antennae
performance. Therefore, they were neglected as most of the orientation position of the satellite still can
give higher gain and omni-directional radiation pattern results.

![Figure 4 2-D Radiation Pattern Plot](image)

**Figure 4 2-D Radiation Pattern Plot; (a) UHF Downlink (b) UHF Uplink and (c) VHF Monopole Antenna**

### 4. Space Environment Test

#### 4.1. Vibration Test

BIRDS-2 CubeSats underwent vibration test utilizing HTV and SpaceX launch vehicle profiles to ensure
that it will survive the launch environment and still function afterwards. The satellite will endure
vibrations and loads very similar to the ones it will experience on the launch vehicle to ensure that the
design is solid and nothing will break. It also verifies that the lowest resonance frequency of the satellite
is higher than the exciting frequency during the launch. Specifically, vibration test for antenna
configuration on a shaker is mainly to verify the Flight Model (FM) +Y panel structural design and
mechanical requirements. The BIRDS-2 CubeSats are tested in Random QT level of 6.526G and Sine
burst AT of 18.1G. All BIRDS-2 FM structural vibration test result revealed that both antennae; UHF
and VHF did not prematurely deployed as the single fishing line could hold the rolled antennas in a
fixed position. Vibrations did not cause the antenna to slip from the mounted screw and the fishing line survive the constant rubbing against the sharp edges of the antenna.

4.2. Cold Environment Test

The antenna deployment test in cold environment in a thermostatic chamber for the BIRDS-2 FM CubeSat demonstrates the ability of the antenna deployment mechanism to meet qualification requirements under low temperature conditions (extreme temperature) which simulates thermal stressing (extreme cold environment) of the BIRDS-2 CubeSat. It was tested in the chamber within the temperature range of -20 to -40°C concerning five units of burner circuits. By referring the Table 3 which showing the result of antenna deployment in cold environment, the nichrome wire is capable to burn the fishing line and antenna can be deployed within 13 to 18 seconds (average) under the extreme low temperature condition with 80% battery charging capacity. ADCS algorithm is verified to be able to turn ‘ON’ and ‘OFF’ the 3.3V signal to/from the burner circuit within its time. The antenna deployment time, current consumption (during the nichrome wire is burned), initial and final battery voltage (before and after nichrome wire is burned) are analyzed.

Conclusion

This paper describes the approach on designing the antenna deployment mechanism, analysis and testing of monopole antenna on BIRDS-2 CubeSats. Although it is so attractive due to its simple design, low cost and fast development time, it offers many technical challenges especially on the size, power and communication link budget. Due to this, deployable antennae are becoming more of a necessity because the electrical length at UHF/VHF bands and enhancing gain according to the link budget estimation. The chosen material for the deployable antennae also must be flexible and robust for operation in space. Issues addressed in this paper also proved the rigidity of the mechanical support structures [5], accuracy of the deployment time, stowage of antennae during harsh launch environment, and the ability for the antennae to achieve high gain and omni-directional radiation pattern for successful communication.

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| Burner Circuit Label | Temperature (°C) | Current Consumption (A) | Deployment Time (s) | Battery Voltage (V_i/V_f) |
|----------------------|-----------------|------------------------|---------------------|--------------------------|
| 1                    | -30             | 2.068                  | 15.77               | 4.018/3.830              |
| 2                    | -25             | 2.154                  | 15.93               | 3.99/3.90                |
| 3                    | -35             | 2.034                  | 82.22               | 4.00/3.811               |
| 4                    | -40             | 2.045                  | 17.75               | 4.00/3.793               |
| 5                    | -20             | 2.007                  | 13.21               | 4.018/3.832              |