# Development of Antenna Deployment Circuit for Nano-Satellites

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***Abstract*—Nano Satellites generally weighing between 1 and 15 kg, serving the purpose of space research are popularly standardized as CubeSats. The CubeSat standard has made it really feasible and easy for students from various universities to develop their own Nano-satellites with their very own payloads. Antennas are critical components in the onboard communication system of satellites, the Nano Satellites usually communicate in the Amateur Frequency Bands; these bands exist from 144 MHz to 146 MHz in VHF and from 434 MHz to 438 MHz in the UHF range. Designing antennas at these frequencies typically ends up being larger in size than the actual CubeSat itself. Thus generally the antennas for a Nano Satellite are made flexible enough to be folded in order to comply with the CubeSat size standards. Once the satellite is ejected into the orbit from the deployer module, an automated signal is used to trigger a circuit that initiates a series of processes to deploy the folded antennas back into their original shape. This paper deals about the design and development of a highly efficient, smart and reliable control circuit prototype called the Antenna Deployment Circuit. This developed prototype is tested and the results are summarized in the paper.**

***Keywords—Antenna Deployment, CubeSat, Nano Satellite, Control Circuit, Antenna.***

## I. Introduction

In recent years, the size of satellites has been on the fall. This trend has given rise to the involvement of research institutions and educational organizations in the development of their own satellites on a new scale-the nano-scale. One such program that pioneered the Nano-Satellite industry is the CubeSat program conceived by Prof. Robert Twiggs of Stanford University's Space Systems Development Laboratory and Prof. Jordi Puig-Suari of the California Polytechnic State University. This program was aimed at having a production life of one year from the design to the development phase. The size constraints of the CubeSat restrict the volume of the satellite from 1 cubic meter to 3 cubic meters. The upper limit on the total mass of the satellite is 5 kg. Generally, CubeSats as well as the other Nano-Satellites are allocated frequencies in the amateur band for communication purposes as shown in [1]. These frequency bands are situated in the VHF and UHF frequency range and extend from 144 MHz to 146 MHz (2m Band) and from 434 MHz to 438MHz (70cm Band) respectively.

The major challenge faced while operating at these frequencies is the design of the on-board communication antennas. While designing antennas for the optimum performance, the sizes of the antennas become larger than the dimensions of the Nano-Satellite. Thus housing the on-board antennas on the satellite becomes a major concern.

Typically, Linear Wire Antennas are used on-board Nano-Satellites due to their good performance and the ease of their housing. The antennas concerning this text are the Monopole and the Dipole antennas. These antennas are coiled into a stowed position and secured using a strong fiber. A heating element, generally a wire, is used to break the fiber and release the antennas from their stowed position into their deployed position. This heating element is activated only when the satellite is ejected from the deployer module into its specified orbit. The entire process of the antennas being deployed is very crucial in the functioning of Communication Subsystem, the failure of which would lead to the failure of the Communication Subsystem on a whole. Hence this process will have to be reliable, automated and also smart such that minimum on-board power is expended. The Antenna Deployment System was designed, prototyped and tested with this objective.

## II. Objectives

### A. System Requirements

The Antenna Deployment System must be a fast and a reliable system to ensure the quick and successful deployment of the antennas. Moreover it should detect the deployment of the antennas and automatically activate the auto shutdown to conserve power. It should also provide a feedback signal to the satellite's on-board micro-controller (MCU), indicating the status of the antenna deployment. Thus if the first attempt leads to an unsuccessful deployment, the MCU can call for another deployment attempt.

### B. Design Constraints

The Antenna Deployment System should meet the following set of design constraints as per the specification and availability of most Nano-Satellite resources:

1. Consume less than 2 watts of power.
2. Deploy the antennas under 5 seconds.

3. Expend less than 10 joules of energy per deployment cycle.
4. Provide TTL / CMOS signal feedback to the MCU.
5. Occupy less than 2.54 square centimeter of printed circuit board area.

## III. System Design

In this section, the complete system design will be described giving emphasis to meet the objectives of the system. Special care has been taken to ensure that the design lies within the design constraints of the satellite. The principle of working of the deployment mechanism lies in breaking the fiber securing the stowed antennas. In order to break this fiber, the temperature of the heating element should surpass the melting point of the fiber. The material of the on-board antennas also has an important role in deciding the fiber that will be used to hold them together in the stowed position. Since all the components are interdependent on each other, the design process flow will begin from the physical aspect and the final goal will be the design of an appropriate electronic circuit to control the deployment process.

The selection process of the various components is as follows:

### *A. Antenna Design*

Most nano-satellites have been assigned one frequency in the VHF and another in the UHF range. Considering the allocation of 145.5 MHz in the VHF band and 437 MHz in the UHF band, the best possible configuration of antennas is a monopole in the 2m band and a dipole in the 70cm band. This conclusion is made based on the rigorous antenna simulations performed on Ansoft HFSS and is different from [2]. These simulations also helped in deciding the position of the antennas keeping the inter antenna interference and loading to minimum. The results of these simulations lead to the final dimensions of the antennas:

TABLE I. ANTENNA DIMENSIONS

| **Parameter** | **Antenna** | |
|---|---|---|
| | ***Monopole*** | ***Dipole*** |
| Length | 560 mm | 316 mm |
| Width | 2 mm | 2 mm |
| Thickness | 0.4 mm | 0.3 mm |

A comparison between the dimensions given in Table I and the actual size of the 2U Nano-Satellite proves that the antennas will have to be stowed and later deployed. Thus we need to select a material that is flexible and also elastic so that the antennas spring back to their original orientation once deployed. Simultaneously, the material should be a good electric conductor and robust. Taking into account all the requirements of the antennas, Beryl-Co alloy was selected since it satisfies all the constraints. It has also been used successfully in many Nano-Satellite missions.

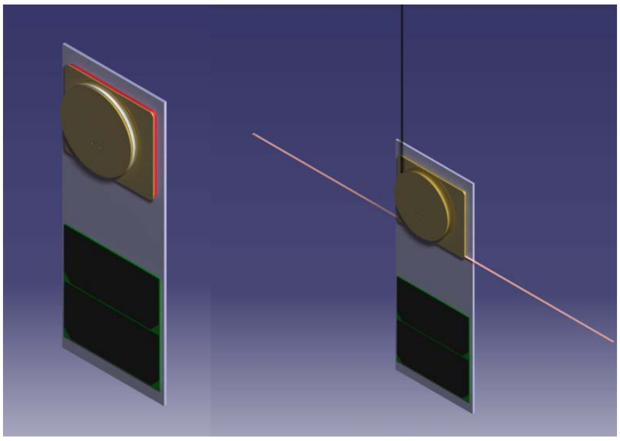

Figure 1. CATIA rendering of Antennas Stowed (left) and Antennas Deployed (right).

### *B. Selection of Fiber*

- The primary requirement of the fiber is high yield strength; it should be able to withstand the high tensile loads experienced during the launch of the satellite and also resist snapping under the tension applied by the coiled antennas.
- The secondary requirement of the fiber is low melting point; so that the less power will be expended in the breaking of the fiber, hence resulting in lesser time to break and thus enabling quick deployment.

To satisfy the above requirements, Dyneema was chosen. Dyneema is the brand name for Ultra High Molecular Weight Polyethylene. The yield strength of Dyneema is typically around 25 MPa and the melting point is around 144 to 152$^{0}$C. Appropriate diameter and length of the Dyneema has to be selected as per the design; Dyneema having diameter of 50 - 100μm is preferred.

### *C. Heating Element*

The easiest way of implementing a heating element to burn the Dyneema is using a high resistance wire preferably Nichrome because of its wide availability and simple set up. Thus Nichrome 80 was selected. Assume that the supply rail voltage from the Power Subsystem of the satellite is 3.3V. All the calculations for the heating element depend on this rail voltage and the Nichrome specifications given below:

TABLE II. NICHROME SPECIFICATIONS

| **Wire Gauge (AWG)**[a] | **Temperature (Celsius)** | | |
|---|---|---|---|
| | ***205º*** | ***315º*** | ***427º*** |
| 30 | 0.92[b] | 1.19 | 1.47 |
| 32 | 0.68 | 0.90 | 1.13 |
| 34 | 0.5 | 0.68 | 0.83 |
| 36 | 0.38 | 0.52 | 0.63 |

a. American Wire Gauge Standard, b. Current in Amperes.

The above Table II shows the current values that are required to raise the temperature of the different gauges of Nichrome to the specified temperature. Temperature of $205^0$C is sufficient to melt the Dyneema, and 34 AWG Nichrome is best suited for our application in terms of yield strength, current consumption and mechanical stability. Hence the 34 AWG Nichrome 80 alloy wire was selected to be used as a heating element in the Antenna Deployment System. A current of 0.5 A is supposed to be drawn by the wire to heat it to $205^0$C.

The resistivity of 34 AWG Nichrome at $20^0$C is about 53.75 Ω/m. Assuming the average length of the Nichrome wire in the Nano-Satellite to be around 2.54cm, the resistance of the wire is calculated using equation as in (1) derived from [3]; the result of which is given in (2).

$$\text{Resistance} = \text{Length of Wire} * \text{Resistivity} \quad (1)$$

$$\text{Resistance} = 0.0254\text{m} * 53.75\Omega/\text{m} = 1.365\Omega \quad (2)$$

From Equation (2) and using the Ohm's Law, the voltage required across the Nichrome of length 2.54cm in order to draw a current of 0.5A is 0.69V. Accordingly a resistor will have to be used in series with the Nichrome to form a resistive voltage divider and ensure that at most only 0.69V drops across the Nichrome. Let the resistance to be connected in series be called $R_s$, the value of $R_s$ can be determined by applying the Kirchhoff's Voltage Law shown in (3).

$$3.3\text{V} = 0.5 * R_s + 0.5 * 1.365 \quad (3)$$

$$R_s = 5.235\Omega \quad (4)$$

The value of $R_s$ is calculated and given in (4). The resistive divider will be incorporated along with additional electronic circuitry to support the features mentioned in the system requirements.

Assuming that the typical deployment cycle lasts for about 4 seconds, the power consumed by the resistive voltage divider configuration is theoretically given by (5) and the total energy spent in the 4 second duration is given by (6).

$$P = V * I = 3.3\text{V} * 0.5\text{A} = 1.65\text{W} \quad (5)$$

$$E = P * t = 1.65\text{W} * 4\text{s} = 6.6\text{J} \quad (6)$$

### D. *Control Circuit Schematic*

As shown in Fig. 2, the three essential components that add to the functionality to the previously designed resistive voltage divider set up are:

1. MAX890L OCPC (Over Current Protection Circuit) Switch
2. LMV861 Operational Amplifier
3. SN74LVC1G11 3 input AND Gate

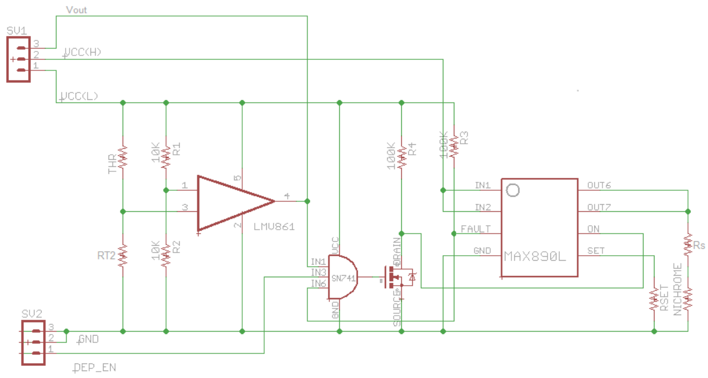


Figure 2. Antenna Deployment System Schematic

The MAX890L is the switch to the resistive voltage divider. It also doubles up as an over current protection mechanism, thereby shutting off the supply in an event of over current through the divider network. This current limit is set by the value of $R_{SET}$ resistor in the schematic, the formula for which is given by (7). Let $I_{LIMIT}$ be slightly greater than 0.5A.

$$R_{SET} = 1380 / I_{LIMIT} = 1380 / 0.6 = 2.7\text{k}\Omega \quad (7)$$

The LMV861 Operational Amplifier is used as a comparator to detect the exact event of the deployment and in turn end the deployment cycle. The event of deployment is detected by accurately sensing the temperature of the heating element using a thermistor. The comparator is used to compare the two bridge voltages as shown in the schematic, the exact temperature at which the deployment cycle will end depends on the $R_{THR}$ resistor in the non-inverting bridge; the value of this $R_{THR}$ should be higher than the value of the thermistor at $205^0$C. This value is calculated using the relation shown in (8).

$$\text{Beta} = T_1.T_2 / T_2 - T_1 * \ln(RT1 / RT_2) \quad (8)$$

Where $T_1$ - 25°C

$T_2$ - 200°C

$RT_1$ – 100kΩ

$RT_2$ – Resistance of Thermistor at $T_2$.

Beta = 3974

Evaluating (8) based on the parameters obtained from the datasheet of Honeywell 135-104LAC-J01 thermistor, $RT_2$ is calculated to be 720Ω. Thus the value of $R_{THR}$ should be 750Ω. This will ensure that the actual temperature at which the deployment cycle will end is below $205^0$C. The Op-Amp is also responsible for providing the MCU with a TTL/CMOS signal to indicate successful deployment of the antennas.

The SN74LVC1G11 AND Gate is used to control the switching of the deployment cycle only if all three criteria below are true:

- Deployment Enable Signal by MCU
- MAX890L No Fault Condition
- Temperature has not exceeded $205^0$C

## IV. PROTOTYPING AND TESTING

### A. *Prototyping*

The schematic shown in Fig. 2 has been implemented on a PCB taking into account the following design considerations:

1. The PCB has to be made using FR4 (glass epoxy) material as in [4].
2. Nichrome heating element has to be placed in contact with thermistor.
3. The VCC (high) track has to carry up to 1A of current.
4. Small board size.

The fabricated prototype is shown in Fig. 3.

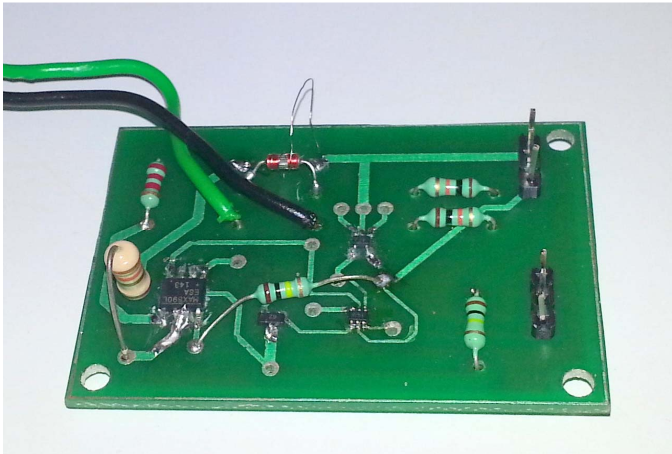

Figure 3. Antenna Deployment System Prototype

The prototype was soldered taking precaution about the static sensitive devices on the PCB, appropriate equipment and ESD protection were used. To prevent the external heat in space from affecting the thermistor resistance and causing erroneous results, we covered the thermistor with heat insulating Kapton tape. Kapton tape has proven to be a successful heat insulator on various space missions since it possesses excellent heat insulation properties as in [5].

### B. *Testing*

The fabricated prototype was tested based on the following test parameters:

1. $V_{CC}$ (high) = 3.3V
2. $V_{CC}$ (low) = 3.3V
3. GND = 0V
4. DEP_EN = 0V (logic 0) and 3.3V (logic 1)

The VCC (high) is used to supply a large current to the heating element whereas the VCC (low) is the rail voltage for the supporting circuitry and thus prevent loading of the battery.

Initial conditions generated by the circuit after warm starts were as in Table III; once the DEP_EN signal was activated (active high) the circuit switched from being into an off state to the on state, the final on state conditions of the circuit are also shown in Table III.

TABLE III. INITIAL & FINAL CONDITIONS

| **Sr. No.** | ***PIN Name*** | **DEP_EN = 0V** | **DEP_EN = 3.3V** |
|---|---|---|---|
| | | ***Voltage*** | ***Voltage*** |
| 1 | FAULT (Active Low) | 3.2V | 3.2V |
| 2 | ON (Active Low) | 3.3V | 0.4V |
| 3 | $V_{OUT}$ | 3.3V | 3.3V |
| 4 | $V_{DS}$ | 3.3V | 0.4V |
| 5 | $V_{NICHROME}$ | 0V | 0.69V |

## V. RESULTS AND CONCLUSION

The deployment circuit tests yielded a Dyneema break time of ~2s and the antenna deployment time of ~2-3s, when tested with the appropriate test parameters and at 1 atm pressure. Theoretically the total deployment time in vacuum will be even lesser.

The system discussed in this paper has been successfully prototyped and can be converted into a generic model for any nano-satellite mission.

The primary application of the developed system is for the deployment of antennas on-board Nano-Satellites, but this model can be employed to deploy any mechanism on the satellite.

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