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Development of Nanosatellite Technology with APRS Module for Disaster Mitigation

Development of Nanosatellite Technology with APRS Module for Disaster Mitigation

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Abstract. Development of nanosatellite technology has enabled satellites to be developed with multiple capabilities for a specific mission in a short time with a low cost. Satellite communications are proved to be more effective in delivering information due to its large coverage area. Surya Satellite-1 will become the first Indonesian nanosatellite developed by undergraduate students. It is designed with low-cost commercial payloads, including an APRS module for communication and operated on VHF and UHF amateur radio frequencies. The mission of the satellites focused on disaster mitigation through APRS communication network with remote stations located on disaster-prone areas.

1. Introduction

Indonesia is an archipelago country which has 16,056 islands. Referring to data from Central Bureau of Statistic in 2015, Indonesia has 3,544,743.9 km² area of sea and 1,913,578.68 km² land area, which means over 60% of Indonesia area was covered by water [1]. The location of Indonesia, above the assembly area of 3 major tectonic plates, makes many volcanoes had arisen on its land [2]. Indonesia also has average rainfall more than 1000 mm per year [3]. These geographical conditions make Indonesia must to stay alert when disaster like flood, earthquake, and volcanic eruption will happen.

National Board of Disaster Management (Badan Nasional Penanggulangan Bencana or BNPB) noted disasters in Indonesia have increased gradually from 2000 until now. BNPB reported there were 2,369 disasters happened in 2016 [4]. Therefore, a quick, low-cost and accurate disasters mitigation system is important and necessary, especially for small islands which are separated from central island. Disaster mitigation designed nanosatellite is an option for these conditions [5,6,7,8,9].

Nanosatellite needs an ability to forward or broadcast data collected from ground segment for disaster mitigation [10,11], APRS is one of suitable payload for this mission. Automatic Packet Reporting System (APRS) is a communication protocol founded by amateur radio member, WB4APR, Bob Bruninga [12]. It is applicable in many fields of study, based on many amateur radio projects that have been made [7,13]. It has open access status which allows anyone who has amateur radio license to communicate with APRS protocol, which is especially practical for emergency communication service when the disaster happened. [14]

There are some differences that APRS has compared to other radio packet. Its features include giving real-time weather data, maps and other data presentations. Since it is integrable with other communication platforms, such as internet, data updates can be disseminated to public in real time. Technically, it provides generic and intelligent digital repeating, a means to relay digital data through a data network, to avoid network flooding and more user-friendly with callsign for each user. While it also capable to do quick broadcasting of text information through full-duplex messaging using AX.25 UI-frame. [13,15]

Surya Satellite-1 (SS-1) is a nanosatellite which brings APRS payload to fulfil disaster mitigation mission. SS-1 will be the first nanosatellite which made by Indonesian students. Interfaces design of this nanosatellite is based on Interface Control Documents from JAXA.

For disaster mitigation purpose, SS-1 three mission goal stages of Minimum, Full and Extended missions have been set as the success indicator. Minimum mission achieved if SS-1 is able to beacon APRS packet data at interval time and ground station will be able to capture the data of that beacon. While, Full mission success achieved if SS-1 has the ability to provide short text messages communication services for disaster mitigation function, such as early fire hotspot warning in forest, or early flood warning, and Extended mission will be to improve education environment in Indonesia in satellite and communication technology with nanosatellite workshop and training for university and high school student.

2. Satellite Development

To fulfil the needs of low-cost satellites for communication and disaster mitigation function, the nanosatellite was designed as a low earth orbit satellite consisting of four common subsystems: Electrical Power System (EPS), Data Handling System (DHS), Payloads which are radio communication modules and Antenna Deployment System [16,17,18,19]. These subsystems are enclosed in aluminium case structure based on JAXA Interface Control Document (ICD) for satellite design.

Electrical Power System (EPS) is responsible for harvesting, storing and distributing power for satellite [20,21,22]. EPS includes current limiting and battery protection function for safety measures. The system consists of GaAs triple-junction solar cells as a power source, Maximum Power Point Tracking (MPPT) as power absorption optimizer, charge controller as battery protector, ideal diode as current limiter, battery as energy storage media, boost converter for regulated 5V power source. [23, 24]

Data Handling System (DHS) function as satellite monitoring and control system [21,25,26,27]. Monitoring includes battery voltage as battery state of charge (SOC) indicator, battery temperature for heater operation indicator, and charging current as power production indicator. Furthermore, additional temperature sensor is attached to measure satellite environment temperature for future studies. On the other side, controlling includes timer, antenna deployment, battery heater, and subsystem power switch control. DHS consists of On-Board Computer (OBC) as data processor and system decision maker, sensors for monitoring, signal converter for bi-directional data conversion between microcontroller and radio modem, and power switch to control power flow. [28,29,30]

SS-1 consist of two APRS payloads, one in UHF-band for uplink channel while the other is VHF-band for downlink channel. Both frequencies have been set to work in half-duplex mode, meaning they can receive and transmit signals at VHF-band and UHF-band, but not to do both at the same time. Each payload consists of APRS module, which converts radio wave data to digital data and vice versa, APRS Tracker as On-Board Data Handling (OBDH) unit, and monopole antenna since it does not have altitude control function [31]. The architecture of communication system is shown in figure 1 below [32], while the whole subsystem configurations are shown in figure 2.

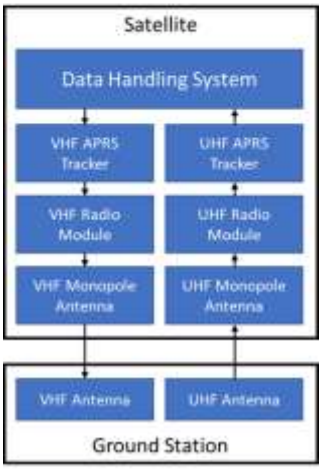

Figure 1. Communication Architecture.

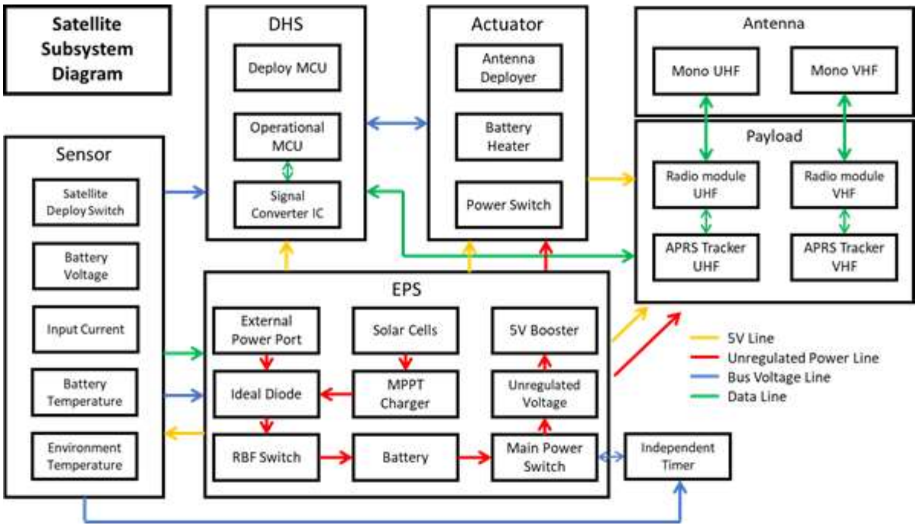

Figure 2. Satellite Subsystems Diagram.

Antenna deployment system is mechanism for folding the antenna before satellite launch and to deploy it at the right altitude [33,34,35,36]. It is responsible for deploying two monopole antennas. Initially, both antenna will be concealed inside the deploy module in nanosatellite by using nylon string to hold the Polytetrafluoroethylene (PTFE) gate cap. To deploy the antenna, the system injected nichrome wire with high current electricity from the battery to heat up nylon string until it breaks off. Once the nylon string is broken, PTFE gate will open, antenna will be deployed, and two limit switches at each antenna will give feedback to OBC to stop nichrome wire heating and indicate successful antenna deployment. Below are procedures needed to launch the nanosatellite via International Space Station (ISS) nanosatellite launcher module shown in figure 3.

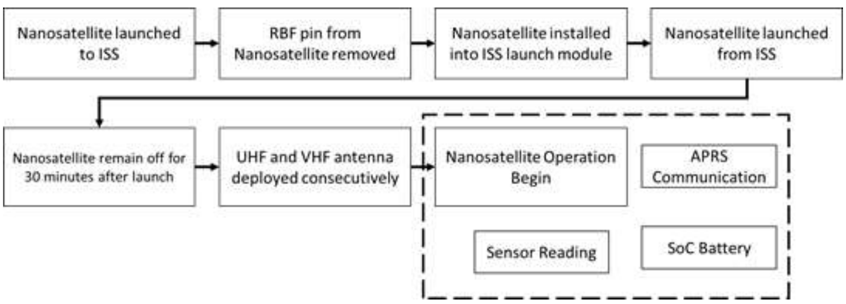

Figure 3. Nanosatellite launching procedures with ISS nanosatellite launcher module.

Produced nanosatellite model will be accepted if it passes vibration test, vacuum test, thermal test, and radiation test. Vibration test will simulate the vibration at the magnitude that satellite will experience during rocket launching. JAXA ICD dictates the magnitude of vibration Quasi-Static Acceleration to be above 8G with additional random vibration test on various frequency depends on launch vehicle used. Vacuum test simulates near 0 Pa depressurization in space environment, with depressurization rate depends on rocket type. Temperature test ranging from -15 °C to 60 °C in Low Earth Orbit environment. Lastly, RF radiation test which limits allowable Electric Field level and allowable Power Density for each VHF-band and UHF-band, including output power limit for exceptional cases. [37]

3. Mission Analysis

The mission of SS-1 will be reviewed through simulation using the AGI STK software [38,39,40,41] [42,43]. Simulated objectives of the CubeSat will be as follows:

1. Able to cover over Indonesian Region at least once a day
2. Able to receive or transmit to a remote station
3. Have at least a year lifetime

The CubeSat simulation parameter will be similar to the simulation of MYSAT nanosatellite, starting from its deployment from ISS to its designated orbit with the nanosatellite launcher module [44]. The simulation scenario was plotted for a year from 1 Jan 2018 05:00:00 UTC until 1 Jan 2019 04:59:59.999 UTC. The modelled nanosatellite can only be tracked 30 minutes after the deployment due to the operating conditions mentioned in the JAXA ICD. Initial conditions of the satellite will be shown in table 1.

Table 1. Initial Conditions of Surya Satellite – 1.

Orbital Elements	Value
Semi-Major Axis (Km)	6775.734821
Eccentricity	0.000406
Inclination (deg)	51.714
Right Ascending of Ascension Node (deg)	127.92
Argument of Perigee (deg)	76.008
True Anomaly (deg)	133.805
Apogee Altitude (Km)	400.34877
Perigee Altitude (Km)	394.84687

SS-1 lifetime was predicted with three atmospheric models used, 1976 Standard, Jacchia-Roberts, and NRLMSISE 2000. The 1976 standard model used an idealised version of atmospheric model, while Jacchia-Roberts model considered some environmental data such as solar irradiation. The CubeSat does not equipped with an altitude control, causing it to be dragged by earth gravitational pull until a certain altitude, and finally plunged into the earth atmosphere as shown in figure 4. The three atmospheric models used in the simulation affects the rate of decay of the satellite. The simulation results show that the developed satellite will decay within 0.7 until 1.8 years, which is common for nanosatellite without altitude control. [44]

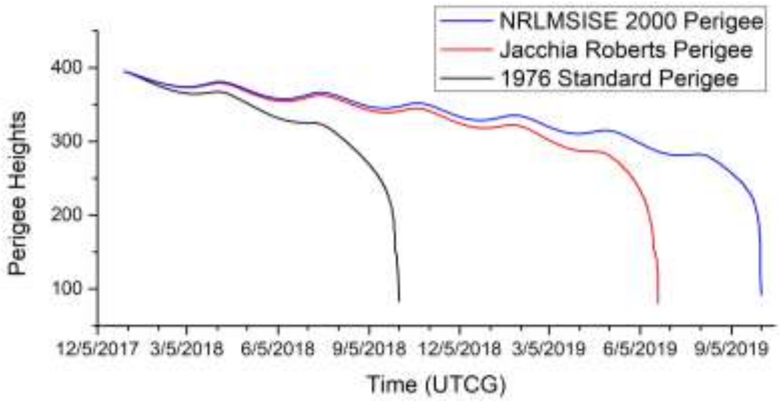

Figure 4. Lifetime Prediction of Surya Satellite - 1 with Different Atmosphere Model (AGI STK Simulation Result).

The CubeSat coverage over Indonesian region was simulated for one-week time range between 2 January 2018 until 9 January 2018 to represent the CubeSat cyclic movement as shown in figure 5. According to the simulation result, SS-1 will pass Indonesia eight times a day, with at least twice has a coverage area more than 70%. Therefore, it is very probable for the satellite to establish a communication with ground stations located in the covered area every day. However, due to the speed of satellite orbit, there would be only a short duration of communications [45,46]. The results of the simulation show that the satellite will obtain maximum coverage area for only 5-6 minutes at a time. Figure 6 shows an illustration of SS-1 radio coverage for more than 50% of Indonesia region.

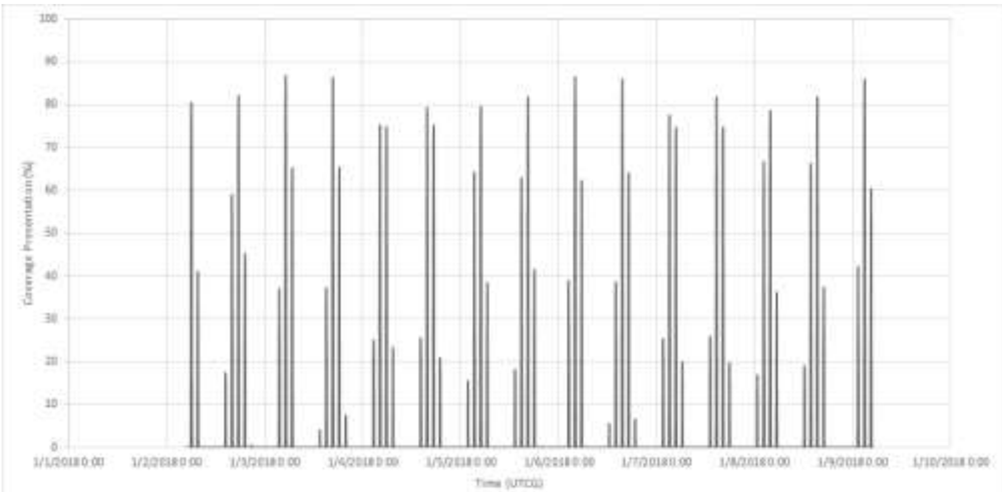

Figure 5. One Week Coverage Percentage of Surya Satellite-1 (AGI STK Simulation Result).

SS-1 ability to establish a communication link to a ground station, during the short time it is within the communication range is determined through the calculation of communication links [47,48,49,50]. The value of received power when communication was made from ground station to the satellite and vice versa could be obtained from equation 1 (Link Budget) and equation 2 (Free space path loss) [45,47,51,52]. Table 2 shows the value of the parameter used and the value of received power when uplink and downlink. Results show that uplink value on UHF was -98.3 dBm respectively, while the designed satellite radio component have a floor threshold of -122 dBm. Downlink power of -107.8 on VHF could be used as the threshold when designing ground station. Therefore, according to the calculation results, it is highly probable for the satellite to establish communication to the ground station.

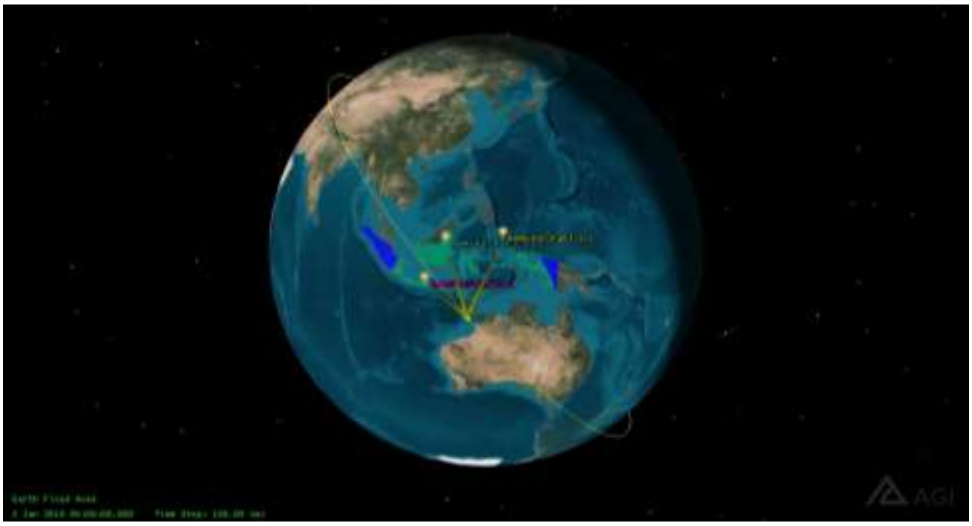

Figure 6. Coverage Illustration of Surya Satellite-1 (AGI STK Simulation Result).

Link Budget

$$\text{Received Power} = \text{Power Output} + \text{Transmitter gain} - \text{Transmitter loss} - \text{Free space path loss} - \text{Misc. Loss} + \text{Receiver Gain} - \text{Receiver loss} \quad (1)$$

Free space path loss

$$FSPL = 20 \text{ Log (distance)} + 20 \text{ Log (frequency)} + 32.44 \quad (2)$$

Table 2. Link Budget Parameter and Calculations.

Parameters	Value
Satellite Antenna Gain (dBi)	0
Satellite Transmitted Power (W)	1
Satellite Antenna Feed Loss (dB)	0.58
Ground Station Antenna Gain (dBi)	13
Ground Station Transmitted Power (W)	5
Ground Station Antenna Feed Loss (dB)	1.5
Frequency (MHz)	435.825
Distance (Km)	1000
UHF Uplink Received Power (dBm)	-98.3
VHF Downlink Received Power (dBm)	-107.8

4. Conclusions

Surya Satellite - 1 has been designed based on accepted launcher standard with the necessary subsystems and APRS payload. The result of the simulation shows that nanosatellite launched from the International Space Station able to circulate around the earth 13 times a day with at least two circulations covered

70% of Indonesia region. Additionally, it has the necessary link budget to send and receive data from ground station. This concludes high probability of nanosatellite development for disaster mitigation.

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