Preliminary Design of Nano Satellite for Regional Navigation System

L Fathurrohim1), R E Poetro1)*, B Kurniadi1), P A Fadillah1) and M Iqbal1)
1) Faculty of Mechanical and Aerospace Engineering, Institut Teknologi Bandung, Indonesia
*ridanto@ae.itb.ac.id

Abstract. A Low cost Regional Navigation Satellite System employing constellation of nano satellites has been proposed for Indonesian coverage. The constellation of Low Earth Orbit nano satellites off course will not be able to give better position fixed to the GPS. However, the design of navigation system has much lower in cost compare to the current navigation system. This paper tells about preliminary design of the proposed regional navigation satellite system. The results of our satellite design has 3 kg on its weight, 10 W on power requirement at the peak condition, and 2.7 years of lifetime. Payload communication of the satellite will use UHF and TT&C communication will use VHF. Total area of solar panel will be 0.11 m².

1. Introduction
Navigation satellites already guide planes, ships, spacecraft and other devices for a wide range of services. The first operational of satellite navigation system was fielded by the U.S Navy in 1964, and was named the Navy Navigation Satellite System [1]. The system, better known as Transit, was used by the U.S submarine fleet to update a ship’s position and reset the inertial navigation system. Transit saw a limited civil use in the maritime industry and geodesy starting in 1967, and it was decommissioned in 1996. Unlike Transit, Global Positioning System (GPS) is based on an idea that is both very simple and quite ancient: one’s position, e.g., coordinates (x,y,z) can be determined given distances to objects whose positions are known. What is fancy in GPS is the realization of this idea with the technology of the late twentieth century in a global navigation system with capability to provide estimates of position, velocity, and time to an unlimited number of users instantaneously, continuously, and inexpensively [2].

The GPS receiver takes the information from 4 satellites to tri-angulate the user's exact location and fixed the time. Nowadays GPS is widely applied on airplanes, helicopters, naval warships, ground vehicles as well as the military troops. Global Positioning Systems (GPS) have become one of the most important technologies to the U.S. military since its development in the mid-1900 [3]. As well as U.S military, Indonesian military also start using GPS technology to support and improve its military capabilities. Satellite navigation is necessary applied to military missions for navigation purposes in enemy territories, and are especially important in absence of light in night missions. Indonesia, with wide area of territory, depends highly on GPS technology. The popularity of GPS underlined the strategic importance of navigation satellites to military services. In a quest for technology independence, Indonesia should have their own navigation system.

The CubeSat specification was developed at Stanford University and the California Polytechnic State University, San Luis Obispo in 1999 to facilitate the participation of science and engineering students in academic satellite development programs [4]. Evolution of the original picosatellite specification of...
a 10x10x10cm cube with maximum mass of 1 kg (a 1U CubeSat) has since resulted in the standardization of larger 2U and 3U nanosatellites. Additionally, an increasing interest in the use of standardized CubeSat components has become more affordable.

In this paper, we introduced a preliminary design of navigation system using nanosatellites. The potential benefits of nano-satellites lie in significantly lowering mission costs and reducing the time to completion for individual spacecraft. The code name of the satellites is “Nanas”, which stands for “Nano Navigation Satellite”.

2. Mission Requirement

2.1. Navigation Satellites Comparison

Table 1 shows data of navigation satellite, compiled from references. All of global navigation satellites are located at Medium Earth Orbit (MEO) which has the altitude of 20,000 km and operated at L band spectrum frequency. However, the current navigation satellite has a lifetime for more than 10 years. Therefore, the size of the satellite never be in the microsatellite class. Since the satellites are located in high altitude orbit, they must provide a small amount of error in determining the user position.

| Navigation System | Owner     | Number of Satellite | Type | Coverage | Satellite Frequency | Satellite Weight | Accuracy (military) | Source(s) |
|--------------------|-----------|---------------------|------|----------|--------------------|------------------|--------------------|-----------|
| GPS                | United States | 32                  | MEO  | Global   | L band             | ~1500 kg         | 0.02 m             | [16] [17] |
| QZSS               | Japan     | 3                   | GSO  | Regional | L band             | ~4100 kg         | 0.02 m             | [18] [19] |
| GLONASS            | Russia    | 24                  | MEO  | Global   | L band             | ~7000 kg         | 0.02 m             | [22]      |
| BeiDou             | China     | 21                  | GEO MEO | Global | L band             | ~4600 kg         | 0.1 m              | [21]      |
| Galileo            | European Union | 30                | MEO  | Global   | L band             | ~1000 kg         | 0.02 m             | [20]      |
| IRNSS              | India     | 7                   | GEO GSO | Regional L band | S band         | ~1500 kg         | 0.1 m              | [23]      |

2.2. Space Segment Constraint

The size of the satellite is another important parameter in the determining the cost in a navigation system. However, Nanas satellite should give an alternative of independent navigation system with the low cost of manufacture. Therefore, the satellite size must be in the class of nanosatellite. Nanosatellite has a weight in less than 10 kg (see Table 2) [5]. In this study, the design of navigation system is restricted with the total cost of less than $4,000,000 and has at least 2 years last for its mission.
### Table 2. Typical small satellite mass classification [5]

| Classification  | Mass Range [kg] |
|-----------------|-----------------|
| Femtosatellite   | 0.001 – 0.1     |
| Picosatellite    | 0.1 - 1         |
| Nanosatellite    | 1 – 10          |
| Microsatellite   | 10 – 100        |
| Minisatellite    | 100 - 1000      |

#### 2.3. User Segment Objectives
In this study, we specify the requirement of Nanas navigation system. As it will become a regional navigation for Indonesia, Nanas navigation must provide a coverage in all Indonesia territory. However, the accuracy of Nanas navigation system should be less than 10 meters in determining the user position and produce bit error rate in less than $10^{-5}$. Another important thing, time access for user, should be always available in all the time of operation. The design requirements of Nanas navigation system are shown in the Table 3.

### Table 3. Design requirements

|                        | Continuous access |
|------------------------|-------------------|
| Time access            | 10 m              |
| Accuracy               |                   |
| Bit Error Rate         | $10^{-5}$         |
| Lifetime               | 2 years           |

#### 3. Constellation Design

##### 3.1. Satellite Constellation
Preliminary design of navigation system start with study of satellites constellation. Satellites constellation was designed well in order to cover all Indonesia region with a tolerable error. The altitude of the satellites are restricted at LEO orbit which has altitude 500 – 1500 km. However, the accuracy of navigation system depends on the value of dilution of precision (DOP), which is the idea that position error that results from measurement errors depends on the user/foghorn relative geometry [6]. Therefore, the DOP value decreases as the satellites separate slightly between each other. Based on DOP requirement, Nanas satellites should be located in the northern part and southern part of Indonesia region once they passed above. As the altitude of the satellite goes down, the number of satellites should increase in order to have more access from a particular user. The altitude of the satellite was set at 1500 km, as we want to minimize the number of satellites required to produce a good repetition in the user access.

However, Nanas satellite parameters orbit were designed based on fact that Indonesia region is located around equatorial. Therefore, satellites inclination is set at 20 degree in order to give an access to the border region of Indonesia. We set the total number of satellites at 32 within Nanas constellation, which are divided into 4 groups by 4 different orbit planes (see Table 4 and Figure 1) [7]. The difference between each plane was set by RAAN value and each member in a group was separated by the value of true anomaly. Nanas navigation system has a mission to provide a regional navigation system around
Indonesia territory. According the mission, the Nanas satellites will be activated once they are in the Indonesia region autonomously.

Table 4. Satellite’s orbit parameters

| Parameter       | Satellite Group 1 | Satellite Group 2 | Satellite Group 3 | Satellite Group 4 |
|-----------------|-------------------|-------------------|-------------------|-------------------|
| Orbit’s Shape   | Circular          | Circular          | Circular          | Circular          |
| Altitude [km]   | 1500              | 1500              | 1500              | 1500              |
| Inclination [deg]| 20                | 20                | 20                | 20                |
| RAAN            | 0                 | 90                | 180               | 270               |
| Number of Satellite | 8            | 8                 | 8                 | 8                 |
| Separation Method | True Anomaly     | True Anomaly     | True Anomaly     | True Anomaly     |
|                 | separated by 45°  | separated by 45°  | separated by 45°  | separated by 45° |

3.2. Launcher Selections

The cost of small satellite development is driven down through use of simplified and standardized commercially available bus, the impact of launch cost becomes highly significant compared to the total mission budget [5]. The current opportunities for launch of small satellites to LEO, see Table 5 and Table 6, are distributed between dedicated launch by a small vehicle provider, launch as part of a rideshare agreement or cluster launch, or by piggyback where the satellite is classed as secondary payload and utilizes excess capacity on a scheduled launch. In each case, a compromise between the cost of the launch, date of launch, and access to the desired orbit is required.
Table 5. Current LEO launch vehicle [8]

| Vehicle     | Origin | Manufacturer          | Reference Payload [kg] | Cost [USD] |
|-------------|--------|-----------------------|------------------------|------------|
| Proton-M    | Russia | Khrunichev            | 21,600                 | $93M       |
| Delta IV    | United States | United Launch Alliance | 22,950                 | $300M      |
| Falcon 9    | United States | Space X | 16,625                 | $68M       |
| Ariane 5E   | Europe  | EADS Astrium          | 21,000                 | $220M      |
| Atlas V     | United States | United Launch Alliance | 17,100                 | $222M      |
| PSLV        | India  | ISRO                  | 3,800                  | $16M       |
| Rokot       | Russia | Khrunichev            | 1,950                  | $14M       |

Table 6. Available rideshare and piggyback launch price [9]

| Vehicle            | Form/Mass | Cost [USD] |
|--------------------|-----------|------------|
| Athena IIc         | 3U        | $300k      |
| Space X Falcon 9   | 3U        | $200k-$325k|
| Antares            | 180 kg    | $4.95M     |
| PSLV               | 300 kg    | $6.95M     |

The clear advantage of dedicated launch however, is that the destination orbit of the payload can be selected to best fit the mission and the date of launch can be chosen to coincide with the payload development and mission operation schedule. More value of dedicated launch however is the flexibility of the spacecraft bus and subsystems, which in turn has an effect on the cost of development and manufacture of the spacecraft itself. For nanosatellite and picosatellite classes, in particular those designed and built by educational institutions, the cost of dedicated launch is usually can not be afforded by the system budget. In order to reduce the cost of launch, Nanas satellite is designed to rideshare or piggyback launch.

4. Subsystems and System Sizing

4.1. VHF UHF Transceiver

The VHF receiver (see Figure 2) is a single frequency crystal-controlled device, operating at a selected frequency in the 140-150 MHz band. The uplink modulation scheme is audio frequency shift keying (FSK) which ensure that the receiver is compatible to our existing Ground Station uplink facilities. The nominal uplink data rate is 1200 bit/s, which ensures that the signal bandwidth remains within an amateur radio communications.

However, The UHF transmitter is designed to operate between 420-450 MHz. It delivers around 500 mW of radio-frequency (RF) power. The downlink modulation scheme is nominally binary-phase-shift-keying (BPSK) with G3RUH scrambling, but Gaussian-minimum-shift-keying (GMSK) with G3RUH scrambling are also supported. The nominal data rate on NANAS was fixed at 1200 bps. Total cost for communication handling is $3,960.
4.2. Power System
The spacecraft was designed to generate power through four deployable solar panels, each populated with 20% efficient GaAs cells (see Figure 3) producing, nominally 0.5A per panel at 12V. The solar panel includes an integrated temperature sensor. Because of the mechanical configuration of the satellite, the total orbit average power available is approximately 8.4 Watt. However, the minimum required bus power is only 800 mW (which represents only the receiver and power system being on), thus, under nominal power conditions these systems, the attitude and orbit control system (AOCS) cab be continuous use. Each solar panel has its own independent battery charge regulator (BCR). The BCRs charge a single 8.1 Whr NiMH battery to give a nominal 6V. The total mass of the battery pack is 375g, which gives a relatively high energy density of 21.6 Whr/kg. Total cost for power system is $4,000.

4.3. Attitude and Orbit Control System
The attitude and Orbit Control System (AOCS) is designed to allow 3-axis momentum-biased operation, with autonomous orbit maneuver. Attitude knowledge is provided via a compact CubeSense (see Figure 4 left). It provides an accurate sun and nadir pointing, also compatible with CubeSat standard. Processing of nadir and sun pointing can be done onboard, has dual dual FPGA/SRAM system for redundancy. The sensors required 100 mW for its power consumption and it has total mass 80g. The attitude stabilization and control is provided by a compact MAI-400 Reaction Wheel (see Figure 4 right). It has specification of momentum storage nominally around 9.35 mNms at 10,000 rpm. It delivers maximum torque 0.635 mNm. Total cost for AOCS sub-system is $2,600.
4.4. On Board Computer
The On-Board Computer (OBC) uses a $00 MHz ARM9 processor in a compact ISIS On-Board Computer (see Figure 5). It nominally operates at 3.3V and has total mass 94g including FM daughter board. Data storage is provided using redundant SD Card storage 2x2GB with failsafe FAT journaling file system. The On-Board Computer enhances the spacecraft’s capabilities, providing automatic control of the spacecraft. Total cost for OBC sub-system is $6,200.

4.5. Mechanics
The Nanas satellite primary structure consists mainly of the standard aerospace aluminium-alloy 3U module boxes (see Figure 6) were used throughout the spacecraft. It will greatly simplify design, reduces manufacture time, and maximizes the ability to deal with design changes in the future works. A simple deployable solar panel was not designed yet for NANAS satellite to allow it to be deployed into the proper position. The total cost for this sub-system is $3100/satellite.
5. Conclusion and Recommendation

The new Indonesian navigation system has been designed at the preliminary phase that cost $3.6M, has met the design requirements. The Nanas navigation system was designed to last for 2.7 years with a continuous access in Indonesia region. Figure 7 shows an illustration of Nanas satellites as well as Table 7 shows their system parameters.

Table 7. Nanas satellite specifications

| Parameter             | Specification                                      |
|-----------------------|----------------------------------------------------|
| Satellite size        | 15 cm x 15 cm x 20 cm                              |
| Satellite weight      | 3 kg                                               |
| Payload frequency     | UHF                                                |
| TT&C frequency        | VHF uplink UHF downlink                            |
| Solar array           | 0.11 m² deployable GaAs cells                      |
| Battery               | 1350 mAh NiMH                                      |
| Max. power consumption| 8.4 Watt                                           |
| Lifetime              | 2.7 years                                          |
The data can be used as a preliminary data to the next study in the detail design. The further calculation about determining error position of this navigation system should be done. Finally, this result can be optimized further to meet a better accuracy results, to meet the military requirements.

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