Preliminary design of communication and power subsystem for micro-satellite with maritime surveillance mission

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Abstract. Vast maritime territory in Indonesia needs satellite technology to prevent illegal activities such as illegal fishing, fuel dumping, illegal transhipment, and trafficking/smuggling. Therefore, this research aims to design a satellite with mission for detecting illegal activities on Indonesian territorial water and ZEE. The satellite will have the capability to receive AIS signal from ships operating in Indonesian territory, and image signature for optical or radar sensor capture it by SAR. The concept of operation is that the satellite will receive/capture the ships information and send the real-time data while passing Indonesian region. Thereafter, the data received is then processed in ground segment to determine suspected ships. In this paper, the discussion focuses on the design of the satellite communication and power subsystem. In this work, LAPAN’s micro-satellite design is selected as the base to determine and size components of the subsystem. Satellite communication link budget was calculated with three alternatives of antenna to determine which one has the best link performance. Afterwards, the power subsystem which consists of solar cell, as the main power generator, and battery units was designed. The result of the work is a preliminary satellite design of the subsystems, that satisfy the satellite mission requirements.

1. Introduction: backgrounds and objectives

1.1. Backgrounds
Illegal maritime activities drains and damages natural resources of a country. To avoid that, maritime law enforcement is necessary. Half of the work is detecting them. One alternative for the means of detection is by monitoring the country’s fishing zones and territorial water using satellite. In this study, the satellite design is limited at preliminary phase, and the design methods for satellite mission and subsystems is as defined by Larson et al. [1]. LAPAN has launched 2 micro-satellites, i.e. LAPAN-A2/ORARI and LAPAN-A3/IPB whose missions are for experimental remote sensing and maritime traffic monitoring using Automatic Identification System (AIS) [2][3]. The flight result of LAPAN-A2 has shown that the combination of AIS and imaging sensor in micro-satellite is very promising for detecting illegal maritime activities [4].

The future micro-satellites of LAPAN, i.e. LAPAN-A5/ChibaSat, are planned also for maritime activities monitoring, in addition to land cover mapping and oceanographic monitoring. SAR payload can operate in all weather, i.e. sun and cloud cover condition, and at night [5] [6]. Here, LAPAN’s micro-satellite design is selected as the base to determine and size components of the subsystem. In detail, this paper discusses the design of communication and power subsystem for satellite with a
mission to detect illegal maritime activities in Indonesia. The design constrain is that the satellite weight should not exceed micro-satellite limit of 150 kg.

1.2. Objectives
The objective of the research is to produce a preliminary micro-satellite communication and power subsystem design that satisfy the satellite mission requirements. Geographically strategic Indonesian maritime zone is traversed for 60% global trading, including Malacca Strait, Sunda Strait, Makasar Strait and Lombok Strait. Over 90,000 ships pass in a year [7]. In addition to monitor such traffic, the satellite mission also is designed in purpose to detect illegal maritime activities in Indonesia’s 3 million km² of territorial water spread along equator. Hence, the requirements for communication and power subsystem should tolerate high data traffic and high duty cycle, in order to be capable to run its missions well.

Generally, communication subsystem in satellite needs three components, which are transmitter, antenna and receiver. Outputs from the design process of communication subsystem are component determination and sizing.

Power subsystem is designed based on the power required for the whole operation of the satellite. The satellite itself is designed to be able to operate in both days and nights, everytime it passes through Indonesia zone. In daytime, satellite gets the power from the sun which then is absorbed by solar panel which then charges the batteries. While in eclipse, power is generated from energy stored in these batteries.

2. The satellite’s operation concept and subsystem design process

2.1. Operation concept
Since Indonesian territory is spread along the equator, to have an efficient maritime surveillance satellite system, the orbit selected should be in low inclination or near the equator as has been done in LAPAN-A2 mission [8]. In order to get 14 passes in Indonesia per day, the maximum inclination is 10°. The main payload of PSLV mission which LAPAN-A2 boarded in 2015, however, brought the satellite to 6° inclination. Therefore, part of South Indonesia, could not be captured with its optical payload. In this design, assuming there will no limit in the orbit placement, the inclination is defined as 10°. To intensify the surveillance mission, the constelation of 2 satellites is selected so that the AIS observation repeat will be twice. The orbit parameters are presented in table 1. The satellites orbit simulation was done using System Tool Kit version 11 from AGI [9], whose orbit track is shown in Figure 1. The simulation was done for the calculation of satellite’s contact time with ground stations, which mean power consumption needed, and the calculation of eclipse time, for power supply available.

| Orbit’s Shape       | Circular            |
|---------------------|---------------------|
| Semimajor axis      | 6971 km             |
| Inclination         | 10°                 |
| RAAN (Right Ascension of Ascending Node) | 0° and 180° |

Table 1. The satellite’s orbit parameters.
As shown in figure 1, two ground stations are employed for the satellites operation, i.e. located in LAPAN’s facilities in Biak (1,17° S, 136,08° E) and Bogor (-6,5231° S, 106,7176° E). Both stations have S-band TTC and X-band receiving antennas of 11 m diameter.

From the simulation, the period of eclipse is one of the results. While period of full orbit is calculated from equation (1) as mentioned in [1]:

$$\frac{T^2}{R^2} = \frac{4\pi^2}{GM_{central}}$$

(1)

When surrounding Indonesia, the satellite is on duty mode, therefore all subsystems are turned on. The tasks in this mode are:

- Receiving AIS data from ships and send them to the ground station
- Payload captures images and sends them to the ground station
- Receiving and sending TT&C (receive command sent for the satellite’s operation, and report its condition every time necessary).

The ground stations processes the data obtained from the satellites, such as overlaying the image and AIS data. If, for example, the ship in the image does not emit any AIS data, then alarm is activated and maritime authorities are notified. Other suspected illegal activities can also be identified using algorithm jointly developed with maritime authorities.

2.2. Communication subsystem design

In this research, the satellite subsystem preliminary design is started from communication subsystem design, then the resulted power requirement is used as the input for power subsystem design. From the concept of operation, communication links required for the missions are:

- uplink to receive signal from ships,
- downlink to send data from ships to the ground stations,
- downlink to send picture captured from payload to the ground stations,
- uplink and downlink each for TT&C.

The details of the link parameters are presented in table 2.
Table 2. The satellite communication link parameters.

| Mission                              | Link          | Band   | Frequency (MHz) | Data rate (kbps) |
|--------------------------------------|---------------|--------|-----------------|------------------|
| Picture transmission                 | Downlink      | X-Band | 8200            | 100000           |
| Ship information transmission to satellite | uplink (AIS1) | VHF    | 161,975         | 9.6              |
|                                      | uplink (AIS2) | VHF    | 162,025         | 9.6              |
| Ship information from satellite to ground stations | Downlink | X-Band     | 8500             | 50000            |
| TT&C                                 | Uplink        | S-Band | 2200            | 200              |
|                                      | Downlink      | S-Band | 2290            | 200              |

At first, the maximum line-of-sight range of the satellite is determined as 2000 km. The initial beamwidth required of each link is set to be 145.08 degrees, to ensure flexibility in satellite pointing during transmission. Three types of antenna are considered: parabolic, helix, and horn. Based on the communication performance on each antenna type, the calculations were then iterated with narrower beamwidth, which are 106.26 degree (when the maximum LOS is 1000 km) and 30 degree. The gain on each antenna type is calculated as formulated in Larson [1].

To estimate the quality of a communication link, the basic parameter is to know the ratio between energy-per-bit received of the signal to noise density obtained, \( \frac{E_b}{N_0} \), calculated by this equation:

\[
\frac{E_b}{N_0} = \frac{PL_tG_tL_sG_r}{kT_0T_s}
\]  

where \( P \) stands for the transmitter power, \( L_t, L_s, \) and \( L_a \) for line loss between transmitter to antenna, space loss and transmission path loss respectively, \( G_t, G_r \) for the transmitting and receiving antenna gain respectively, \( k \) for the Boltzmann constant, and \( T_0 \) for system noise temperature.

Each type of antenna resulted into different link quality, which determines the mission goal. This link performance parameter is declared as link margin, which is:

\[
LM = \frac{E_b}{N_0} - \frac{E_b}{N_0} - Implementation\ Loss
\]  

Parameters to be compared for antenna selection are its weight, dimension, complexity, and performance of link. Selected antenna, as well as frequency and data rate are inputted for link design. Links with the best performance for each mission are then selected. Lastly, antenna, transmitter and receiver use are sized.

2.3. Power subsystem design

Power subsystem design includes solar panel and battery design. Based on mission requirements, satellite have three modes of operation: earth pointing mode, sun vectoring mode and idle mode. Earth pointing mode is the satellites full operation mode, which occurs when passing Indonesian regions. In this mode all components will be turned ON. When the satellite no longer in Indonesian regions, but still in daylight, the mode in change to sun vectoring to optimize the battery charging. The idle mode is done during eclipse.

The power consumption of the satellite components are derived from LAPAN’s micro-satellite data, which is tabulated below:
Table 3. Satellite component’s power consumption.

| Subsystem                  | Consumption (Watt) |
|----------------------------|--------------------|
| Main computer              | 1,88               |
| ACS                        | 19,80              |
| GPS                        | 0,33               |
| SAR                        | 308,75             |
| Payload Data Handling      | 3,50               |
| AIS                        | 2,08               |

The power production calculation started with solar panel configuration as in reference [5], i.e. 4 deployable panels. The solar panel value assumed to be 0.8 for daylight and 0.6 for eclipse, and the inherent degradation is assumed as 0.77 as in reference [1], and sun incidence angle as 23.5°. The satellite life is projected for 5 years.

3. Results and discussions

3.1. Satellite operation simulation

The satellite operation simulation shows that each satellite accesses both ground stations 14 times a day. During the four months of simulation, the average access duration for Biak ground station, is 785 seconds, while for Bogor ground station the access duration average is 751 seconds. Therefore, each satellite access time to Indonesia may be counted as 1536 seconds per orbit or about 25% of orbit period.

From the simulation set in Januari to April 2018, maximum eclipse duration is 2138,85 seconds or about 36 minutes, occurred in March 20, 2018, as shown in figure 2.

![Figure 2](image)

Figure 2. The simulated sun illumination schedule for orbit 600 km with 10° inclination.

As the period of satellite orbit is 5176,40 second calculate from equation (1), the daylight period should be 3037,40 seconds.

The total period of the two satellites orbiting the earth is 130 seconds, resulting in ground track repetition as 50 minutes. Because the line of sight of AIS covers 10-minute ground track, so the acquisition of data repetition is approximated to reach 45 minutes.

3.2. Communication subsystem sizing

Based on the antenna type, its gain, link margin and size is provided in table 4 below.
Table 4. Comparison of performance of each type of antenna.

| Mission               | Antenna  | On-board antenna gain | Link Margin | Dimension (cm) |
|----------------------|----------|-----------------------|-------------|----------------|
|                      |          | Nearest propagation   | Farthest Propagation |
| TT&C (downlink)      | Parabolic| 1,27                  | 38,04       | 27,58          | 6,3 (dia) |
|                      | Helix    | 1,38                  | 38,14       | 27,68          | 2,1 x 0,4 |
|                      | Horn     | 1,00                  | 37,77       | 27,31          | 1 x 2     |
|                      | Parabolic| 0,68                  | 21,63       | 11,17          |           |
| TTC (uplink)         | Helix    | 1,39                  | 38,49       | 28,03          |           |
|                      | Horn     | 1,01                  | 38,80       | 34,39          |           |
| Image downlink       | Parabolic| 2,38                  | 6,33        | 1,89           | 2,4 (dia) |
| (BW = 106,26°)       | Helix    | 4,08                  | 8,03        | 3,60           | 1 x 1     |
|                      | Horn     | 3,71                  | 7,66        | 3,22           | 1 x 2,4   |
| Image downlink       | Parabolic| 29,54                 | 33,59       | 33,18          | 8,5 (dia) |
| (BW = 30°)           | Helix    | 15,02                 | 18,96       | 14,52          | 7,5 x 1,4 |
|                      | Horn     | 14,64                 | 18,58       | 14,15          | 6,9 x 8,7 |
| AIS downlink (BW = 106,26°) | Parabolic| 2,40                  | 8,68        | 4,25           | 2,3 (dia) |
|                      | Helix    | 4,08                  | 10,38       | 5,94           | 1 x 1     |
|                      | Horn     | 3,71                  | 10,00       | 5,57           | 0,5x0,24  |
| AIS downlink (BW = 30°) | Parabolic| 29,54                 | 35,84       | 35,52          |           |
|                      | Helix    | 15,02                 | 21,31       | 16,87          |           |
|                      | Horn     | 14,64                 | 20,93       | 16,50          |           |

For aiming 100 degree of beam width, parabolic option requires really tiny size which is hard to be manufactured. Horn-typed antenna has problem in implementation since its beam is limited to maximum 106° and having it as the selected antenna might produce a link with the lowest performance among others. For each communication mission, it is found that the best link performances occured when using helix antenna as the medium of radiation.

The advantage of antenna with wide beam is that the satellite can maintain its nadir attitude for imaging during its passing over Indonesia (no need to point to ground station), however, the link budget is very limited. The small link budget could impose communication operation risk. Therefore, to increase communication operation reliability, it is recommended to use 2 kind of antennas, i.e. wide beam and narrow beam. The selected antennas are noted in table 5.

Table 5. Performance of the selected antennas.

| Mission               | Antenna | On-board antenna gain | Link Margin | Nearest propagation | Farthest propagation |
|----------------------|---------|-----------------------|-------------|---------------------|----------------------|
| TT&C (downlink)      | Helix   | 1,38                  | 38,14       | 27,68               |                      |
| TTC (uplink)         | Helix   | 1,39                  | 38,49       | 28,03               |                      |
| Wide beam data transmission | Helix   | 4,08                  | 8,03        | 3,6                 |                      |
| Narrow beam data transmission | Helix   | 15,02                 | 18,96       | 14,52               |                      |

For the components sizing, transmitters and batteries are taken from the products available in markets. Communication subsystem components selected are:

a. Payload data transmission: both image and AIS will use XTx-400 X band transmitter from SSTL. The RF output power is 6 Watt, the power consumption 60 Watt, the weight 5,22 kg and dimension of 14 x 22 x 15 cm [10]. Two antennas which are recommended to be used are as follows.
Helix with 7.5 cm of length and 1.4 cm of diameter. The antenna will provide gain of 15.02 dB with 30° beam.

Helix with 1 cm of length and 1 cm of diameter. The antenna will provide gain of 4.08 dB with 140° beam.

b. TT&C : S-Band Tranceiver to be used has RF output power of 3.5 Watt, power consumption 10 Watt, 1.65 of weight and dimension of 19.8 x 12 x 3.88 cm. The antenna to be used is helix type with 21 mm length, 38 mm diameter and 1.39 dB gain.

3.3. Power subsystem sizing

From communication subsystem design, power required for communication are 60 Watt for data/image transmission and 10 Watt for TT&C. Power consumption for each mode of satellite is as stated in table 6.

**Table 6. Satellite power consumption.**

| Subsystem                | Earth-pointing (Watt) | Sun vectoring (Watt) | Idle (Watt) |
|-------------------------|-----------------------|----------------------|-------------|
| Main computer           | 1.88                  | 1.875                | 1.875       |
| ACS                     | 19.8                  | 19.79                | 19.79       |
| GPS                     | 0.33                  | 0.33                 | 0.33        |
| SAR                     | 308.75                | 0                    | 0           |
| Payload Data Handling   | 3.5                   | 0                    | 0           |
| AIS                     | 2.08                  | 0                    | 0           |
| Comm. subsystem         | 70                    | 0                    | 0           |
| **Total power required** | **406.4**             | **22**               | **22**      |

Based on table 6 and orbit period data from simulation at subchapter 3.1, the satellite power consumption per-orbit when is in the mode of earth pointing is 173.37 W-hr, at sun vectoring is 18.56 W-hr and idle is 14.62 W-hr. The total per orbit power consumption, which has to be fulfilled by per-orbit power production, is 206.5 W-hr. The parameter for solar panel calculation and its result are noted in table 7.

**Table 7. Solar panel calculation parameters.**

| Parameter                                           | Value    | Unit    |
|-----------------------------------------------------|----------|---------|
| Power required for the entire orbit                 | 206.5    | W-hr    |
| Efficiency of solar panel                           | 0.18     | -       |
| Sun flux constant                                   | 1367     | W/m²    |
| Power output with the Sun normal to the cell surface | 252.89   | -       |
| inherent Degradation                                | 0.77     | -       |
| Sun incidence angle                                 | 23.5     | Degree  |
| cosine loss                                         | 0.92     |         |
| Power production capability at BOL                  | 178.58   | W/m²    |
| Power production decrease per year                  | 0.04     |         |
| Actual lifetime degradation                         | 0.83     |         |
| Array's performance at EOL                          | 147.51   | W/m²    |
| Solar array area required                           | 1.4      | m²      |
Based on the bus design from reference [6], in which for the deployable panel size of 50 cm x 50 cm or with the area of 0.25 m², the number of panels required is 6.

Since the lifespan target is 5 years and the frequency of eclipse in a day is 15 times, life cycle required for a battery is 27,375 times. According to Saft Li-ion reference [11], for 30,000 cycle life, maximum DoD (depth of discharge) is 25%.

Highest battery drain happens when passing Indonesia for 25 minutes (operation mode), with the power usage of 406.4 W. Meanwhile the solar panels only supply 221.3 W (direct energy transfer). Therefore, during such time, the battery will have to supply 78 W-hr. Based on the DoD calculation, the battery capacity needed is 308.5 W-hr. Such capacity can be supplied by 4 Li-ion battery with capacity of 84 Watt-hours is required, with per unit has weight of 5.22 kg and dimension of 13.97 x 22.05 x 15.24 cm [12].

4. Conclusions

The preliminary design of communication and power subsystem for micro-satellite with maritime surveillance mission has been done. The constellation of 2 satellites with SAR and AIS payload is selected. The satellite will be able to track AIS transmitting ships in Indonesian territory in near real time, with maximum interval data of 45 minutes. It will also be able to track non-AIS transmitting ships near the ground track of the satellites.

For communication subsystem, trade-off study has been done on various type of TTC and payload data transmission antennas. It is found that the best link performances occured when helical type antennas are used. For payload data transmission, 2 kinds of antennas are used, i.e. wide beam (145°) and narrow beam (30°), to increase reliability.

Based on the orbit simulation, LAPAN’s satellite components power consumption database, and the communication subsystem calculation, the power subsystem is sized. The solar panel needed to produce the power is 6 deployable solar panels that each has dimension of 50 x 50 cm. The battery needed as power storage to support the mission is 4 Li-ion batteries with capacity of 84 W-hr. Each unit has weight of 5.22 kg and dimension of 13.97 x 22.05 x 15.24 cm.

In this research, writers conclude that larger beamwidth results to small value of gain, and tiny configuration of antenna which is impossible to be produced. So, smaller value of beamwidth will be appropriate. Large coverage can be reached by adding satellites and antenna pointing control to receiver.

For further work, these preliminary design can be continued to detail design. Further research can be done in larger power supply for full-day surveillance.

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