THE DEVELOPMENT OF LAPAN'S MICRO-SATELLITE SUBSISTEMS

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ABSTRACT

The paper discusses about the development of satellite bus subsystem bus satelit subsystem done in the Center of Satellite Technology LAPAN (before 2011 known as Center for Aerospace Electronics) in the period of 2009-2013, and its future plan. The objectives of the satellite bus subsystem development is to ensure the sustainability of LAPAN micro-satellite program, and for the satellite technology self-sufficiency, which is the main task of the institute. Three satellite bus subsystems being developed are power control dan data handling (PCDH), reaction wheels, which include their attitude control computer, and star sensor. The choice o the subsystems being developed are due to their importance in satellite system and the capacity of the human resources and facilities in Indonesia. Development steps and their results are presented, and the results from the four years development are used to plan the next technology development phase, i.e. in-orbit test using LAPAN-A4 platform for PCDH, star sensor, and the attitude control computer for 3-axis reaction wheels.

Keywords : microsatellite subsystems, OBC, star sensor, reaction wheels

INTRODUCTION

LAPAN satelit Program is started in 2001, by the submision of proposal for micro-satellite development by Center for Aerospace Electronics. The choice is taken among others due to LAPAN's limited space program budget. The program got funding aproval in 2003, which was implemented by having join micro-satellite development with TU Berlin [ref Hardhienata 2007]. The satellite is named LAPAN-TUBSAT, which was launched by Indian PSLV on January 2007, and until now (mid 2013) still work properly. With the succes of LAPAN-TUBSAT program, in 2008 LAPAN decided to develop its next 2 micro-satellites, which design, integration, and testing procress to be done at the Center's facility in Bogor [ref Triharjanto 2009]. Based on their production series, the satellites are named LAPAN-A2 and LAPAN-A3, which then later named LAPAN-ORARI and LAPAN-IPB.

Mastering the design and integration of micro-satellite, LAPAN started further knowledge building in development of micro-satellite subsystem in Indonesia. The objectives of such development is to ensure the sustainability of the program, in the case that the current subsystem vendor is no longer available. Consideration in the choice of subsystem being developed is the availability of funding, facilities, and human resources in the Center. Based on that, the subsystem chosen to be developed are the satellite main computer or in LAPAN's microsatellite terminology known as power control & data handling (PCDH), reaction wheel, and star sensor [Triharjanto 2009].

TREND ON MICRO-SATELLITE MAIN COMPUTER

Satellite's main computer is the most important electronics in the satellite, since it determined the complexity level of the satellite's operation. Therefore, in every satellite design, satellite main computer is customized. Without the computer's power distribution part, the computer is usually called as on-board computer (OBC).

The OBC on Surrey University's satellites, such as TMsat, Tiungsat, and UoSat-12, are based on intel 386, and therefore, has choice of CAN or ethernet connection system to its pheriperals [ref SSTL OBC386]. Meanshile, the OBC in TU Berlin satellites (TUBSAT) series based on Hitachi series mirocontrollers, in which the connection to the pheriperal is in star configuration (RS232/42) [ref Karim]. The Surrey system has advantage of simpler harnessing, and hardware flexibility when adding pheriperals, meanwhile the Berlin system has advantage on programming simplicity, and quick recovery (reset) in the time of computer error.

LAPAN'S MICRO-SATELLITE MAIN COMPUTER (PCDH)

Due to familiarity and simplicity, LAPAN micro-satellite addopted TU Berlin approach by using microcontroller for its main computer. LAPAN's PCDH consist of PCU (power control unit), which function is to manage electrical power distribution to all satellite components, and OBDH (On Board Data Handling), which function is to receive, validate, decode commands from satellite operator, and distribute them to the subsystems in the satellite. OBDH also process housekeeping data to be sent to the ground station, or to be used by the computer to manage automated operation in the satellite.

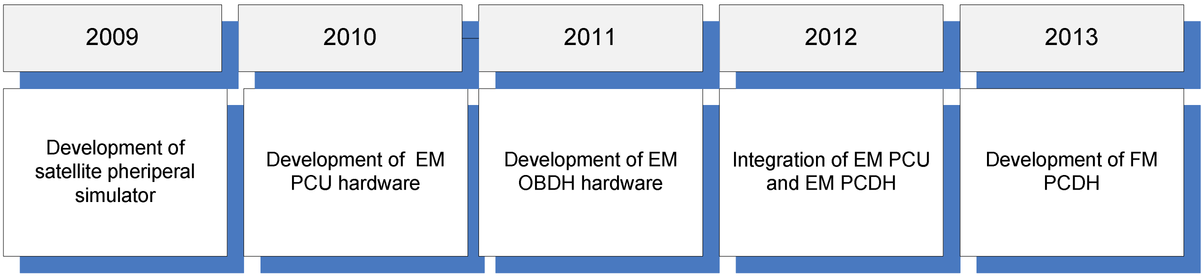

Figure 1. Development steps of LAPAN's PCDH

The development of LAPAN's PCDH is done in 5 years steps since 2009. The first step is developing satellite pheriperal simulator. The objectives of the simulator is to test the OBDH communication system to be developed in PC. The schematic of the simulator is in Figure 2. [ref Triharjanto 2010]

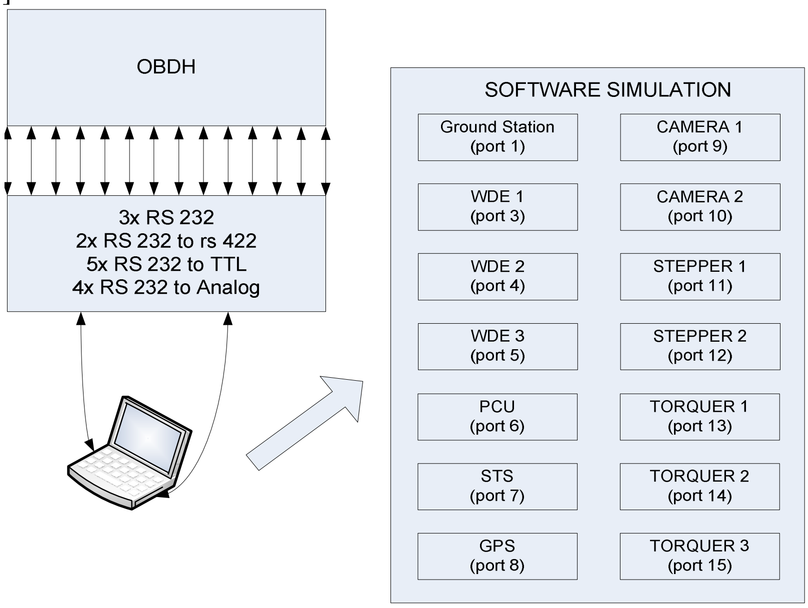

Figure 2. LAPAN satellite OBDH pheriperal simulator

The components of the pheriperal simulator are 3 virtual reaction wheel drive electronics (WDE), 3 virtual magnetic torquers, virtula PCU, and lens focusing mechanism (stepper), since LAPAN's satellite typically carry cameras. The virtual WDE will give back data as requested by OBDH as done in LAPAN's satellite, such as system time, power consumed, control mode, wheel rpm etc. The similar function is done by other virtual pheriperal.

In 2010, the engineering model (EM) PCU is implemented in hardware, and therefore, combined with previous development result to become hardware-in-the-loop (HWIL) simulator. The schematic of the simulator is in figure 3. The step is done to conduct test on the switches, fuses, voltage converters, and voltage and current sensors, in which the control is done by microcontroller. In LAPAN's satellite, voltage and current sensors, as well as temperature sensors are installed to most of the electronics components to check their health.

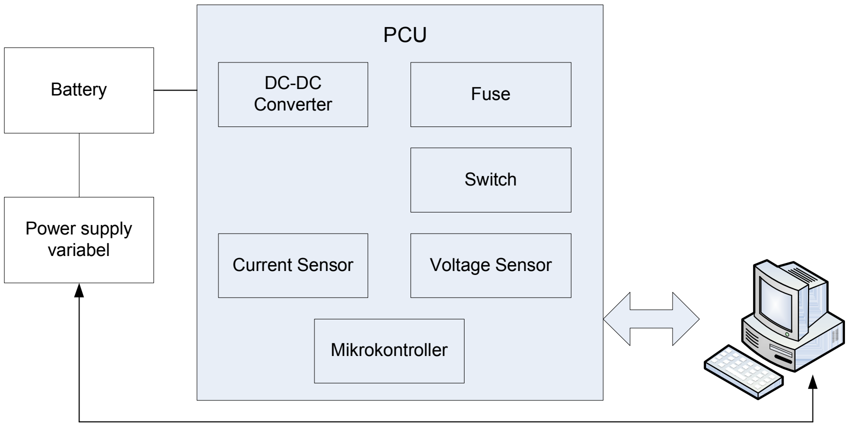

Figure 3. Schematic PCU HWIL

Based on the PCDH design of LAPAN-A2, in which Li-ion bateries are used, then one of the components in the PCU is Battery Charge Regulator (BCR). BCR function is to control the charging and discharging process on the batteries, so that overcharge and over discharge that may damage the baterries can be prevented. Indutrial spec Li-ion bateries are used in the simulation.

Figure 4. Battery Charge Regulator and 14.4 volt 11AH Li-Ion battery

Other components in the PCU is the fuses and switches, which in 2010 development are still in the separate modul. The fuses are to isolate any components that may short-circuited so that overdrawn of current that may damage the satellite can be preveneted. The test of the fuses are done using dummy electrical load, rheostad, while the test for the switches are done using oscilopcope.

Figure 5. Fuses test using rheostad

To process telemetry data, the EM PCU use rabbit 3000 microcontroller. The circuit has ADC and DAC, for the telemery channels, as well as serial comunication interface (SCI). In 2011, additional pheriperal is added in the EM PCU, i.e. the solar panel simulator. The software control the output from power suply as if that the sun ilumation is varied during the satellite flight in orbit. The objective of the simulation is to test the charging of the bateries in orbit condition.

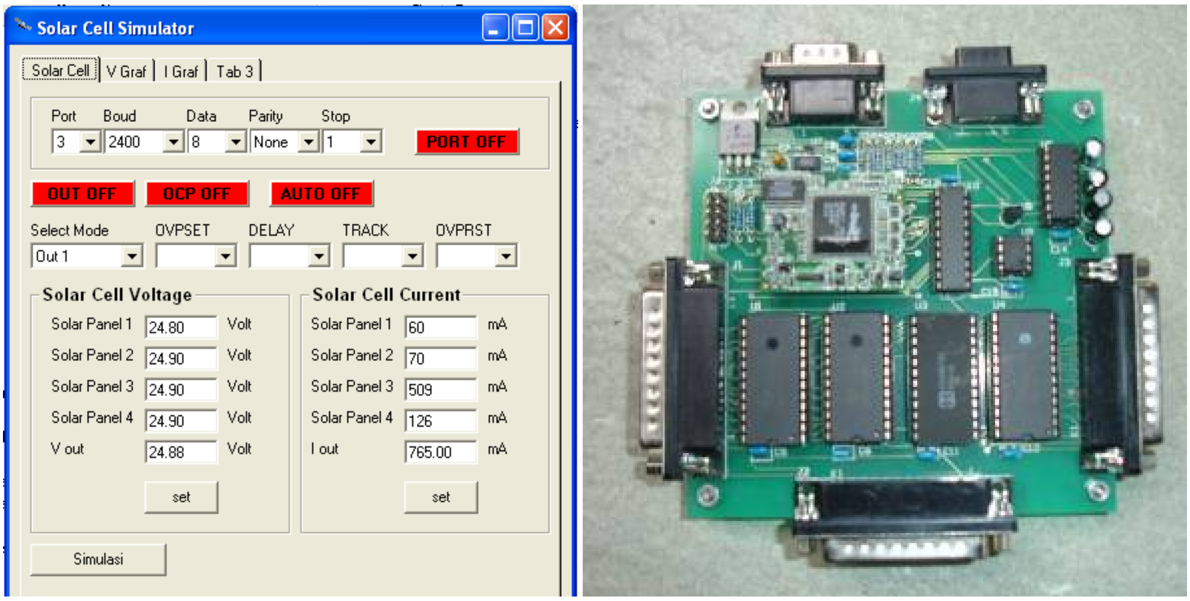

Figure 6. Solar panel simulator software and EM PCU microcontroller hardware

In addition to that, as described in figure 7, software to simulate command from ground station is developed, with the full functions to switch ON and OFF subsystems, taking telemetry (current, voltage, and temperature data of all subsystems).

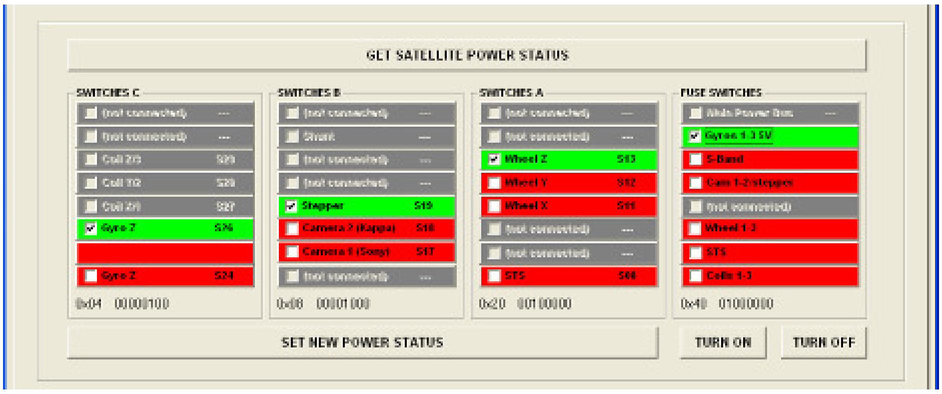

Figure 7. PCU telemetry/command software display

In 2011, EM hardware OBDH based on SH7145 prosesor (Figure 9), the same OBDH prosesor used in LAPAN-TUBSAT, was also built. The integration of the EM OBDH with the EM PCU was done in 2012. With the integration, the switches can now be controlled using the timer function and parameters such as system time for each subsystem can be recorded. Continuous telemetry function (to systematically record the satellite health), scheduled reset, and time time-out call for each subsystem can also be implemented.

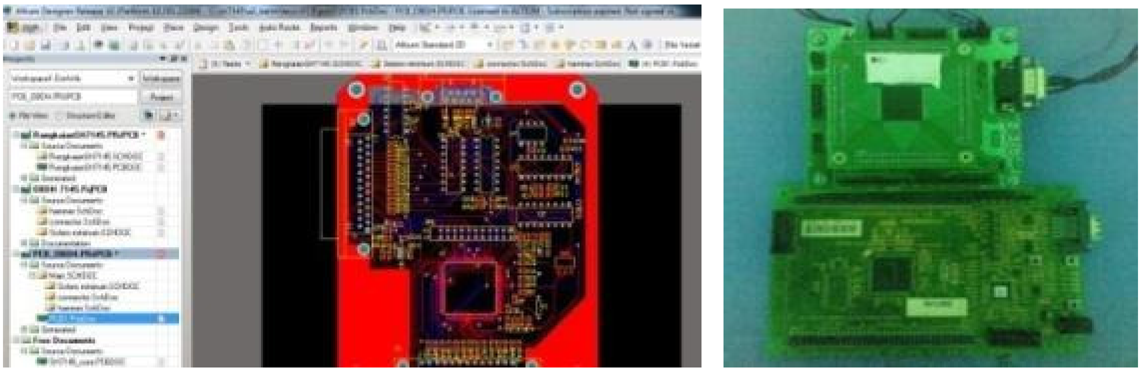

Figure 9. Design and implemenation of OBDH based on SH7145

REACTION WHEEL

Reaction wheel (RW) is the necesary components in satellite with surveillance or remote sensing mission. It functions as attitude actuator, to ensure the satellite camera and antenna points to the Earth. Since the satellite program of LAPAN (ref Suhermanto) mainly focus on Earth observation satellite, the components become crucial to ensure the sustainability of the program.

Technology trend on microsatellite reaction wheel

Some of commecially off-the-shelf (COTS) reaction wheels for micro satellite are shown in figure 10, and their parameters are tabulated in table 1.

Figure 10. COTS reaction wheel IRE 303, RSI04-33, MW200, and SSTL 100P

Table 1. Microsatellite reaction wheel parameters

RW	IRE 303	RSI 04-33	MW 200	SSTL 100SP
Diameter x height (cm)	10 x 7	13 x 11	10 x 9	12 x 12
Weight (kg)	1,2	1,75	0,8	2,6
Ang. Mom. (N.m.s)	2,76	0,4	0,18	1,5
Max rpm	6000	6000	10000	5000
Design life (years)	15	15	5	7
Flown by	LAPAN-TUBSAT	KITSAT (as Teldix's)	Fedsat, Xsat	Surey/SSTL series

From the table above, it is shown that IRE 303 has smaller dimension and weight while able to provide higher angular momentum compared to others. Therefore, it is chosen as the template for LAPAN's reaction wheel development.

LAPAN Reaction Wheel

Reaction wheel consist of inertial wheel, with embeded rotation sensor, and control electronics. LAPAN's inertial wheel is produced with permision to replicate the design from IRE 303, while its control electronics is developed in LAPAN, to permits capacity expansion and avoid risk on electronics components continuity supply. The development steps is shown in figure 11.

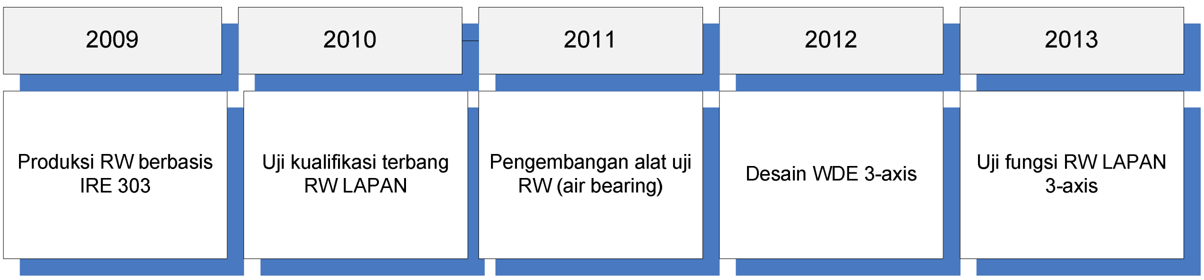

Figure 11. Development steps of LAPAN's reaction wheel

In 2009, 2 reaction wheels were produced by LAPAN, in addition to their associated 2 wheel drive electronics (WDE) [ref Maydita 2010]. The challange in developing the the hardware in Indonesia is finding the equipments to balance the inertia wheel and to test the leak on the pressurized wheel's casing. The balancing is done in early 2010, using the avionic workshop at Garuda Maintenance Facilities (GMF), that were used to balance mechanical gyroscope (see figure 12). The leak test was done after establishing simple vacuum test chamber at Center for Satellite Technology. The chamber was modifed from low pressure chamber previously used by Center for Atmospheric

Science of LAPAN to test high altitude atmosphere sounding instruments. Beter seals and new vacuum pump were installed, so that the air pressure in the chamber can go down until 5 mbar (see figure 13).

Figure 12. Inertia wheel in balancing equipments being tested at 2000 rpm

Figure 13. Reaction wheel's leak test in LAPAN vacuum chamber (left) vacuum gauge showing pressure in mbar (right)

As planned in the development steps, in 2011 test equipments was established to test the performance of the reaction wheel control electronics. The wheel control electronics is designed to also read input from gyro and perform close-loop control on satellite attitude. Therefore, the test for such close-loop require air bearing platform. The ball bearing part of the platform, which was the most critical part, is developed in cooperation with expert from optics industries to be able to get the required polished surface. Due to its high surface smoothness, the air bearing can lift up to 50 kg with 5 bar air pressure.

In 2012, the development of WDE with the capacity perform 3-axis control on the satellite was started. This mean that the electronics will control 3 RW and getting input from 3 gyros, and the posibility of also involving 3 magneto-torquers and a star sensor. The electronics are planned to be tested in the mid of 2013.

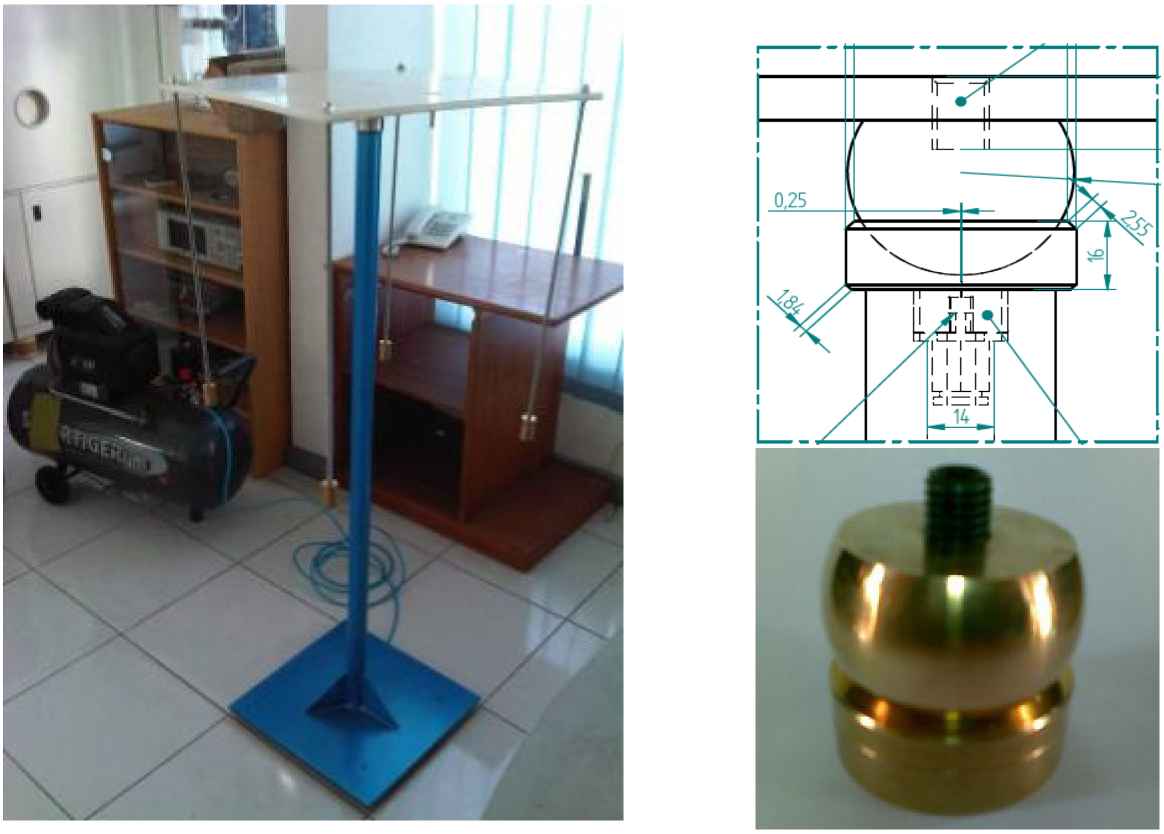

Figure 14. LAPAN's air bearing Platform (right side showing the ball bearing developed)

STAR SENSOR

Star Sensor is the highest accuracy attitude sensor in satellite. The sensor work by taking star images and comparing them with embeded star database. In Earth observation mission, star sensor is necesary sensor, so that the location of the place being imaged is known. The sensor data also become the parameters to perform geometric correction (error due to paralax angle) to the image. Since the satellite program of LAPAN mainly focus on Earth observation satellite, the components become crucial to ensure the sustainability of the program.

Microsatellite star sensor technology trend

Star sensor that available for microsatellite, among others, are VST made by Vectronic (Jerman), mASC made by Denmark Technical University, and ALTAIR made by SSTL.

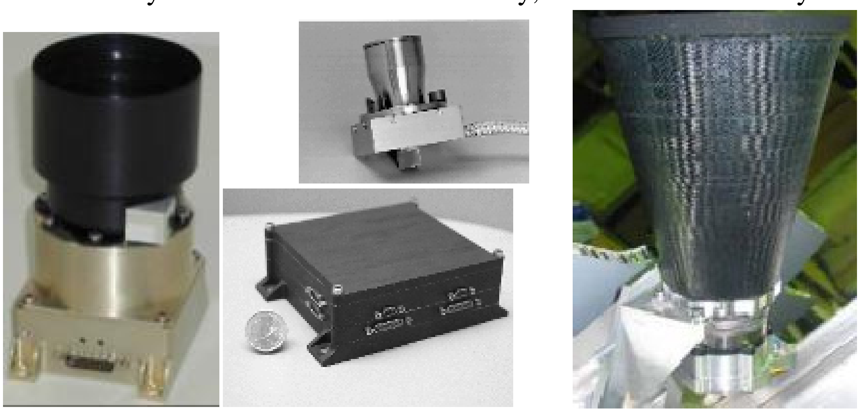

Figure 15. VST, mASC and ALTAIR star sensor (ref Vectronic, DTU, SSTL)

Table 2. Microsatellite COST star sensor parameters (ref Vectronic, DTU, SSTL)

STAR SENSOR	VST-41MS	mASC	ALTAIR HB
Dimension (cm)	15x15x25	10x10x4,5 & 5x5x5 (per head)	17x16x32
Weight (gr)	850	450	2500
Acuracy (arcsec)	18	1	10
Update period (Hz)	4	20	1
Type	CMOS	CCD	CCD
Flown by	LAPAN-TUBSAT	Flying Laptop, Proba	DMC, RapidEye

VST star sensor uses 50 mm lens, so that it has field-of-view (FOV) 14^{o}x14^{o}. The star uses CMOS sensor and 32 bit prosesor. mASC (micro-Advance Stellar Compas) star sensor combine inputs from several optical head to ensure gatting star images at any attitude (could be obstructed by Earth/Moon/Sun). The processing system of the star sensor is superior than others, that it could give up to 20 Hz attitude update. Such performance could replace gyro in the satellite attitude control system. Star sensor Altair, in this comparison, is the heaviest and the biggest, as well as having the lowest update rate.

Theoretically, the more stars being used to determinae the attitude, the higher the sensor accuracy. However, it will require bigger star catalog, which means bigger memory capacity and higher computational load in identifying the stars. Therefore, the development of LAPAN is developed by compromising the objective of getting the highest update rate with the constraints of 32 bit processor.

LAPAN's Star sensor

The development of LAPAN's star sensor is started in 2010, with the roadmap as follows :

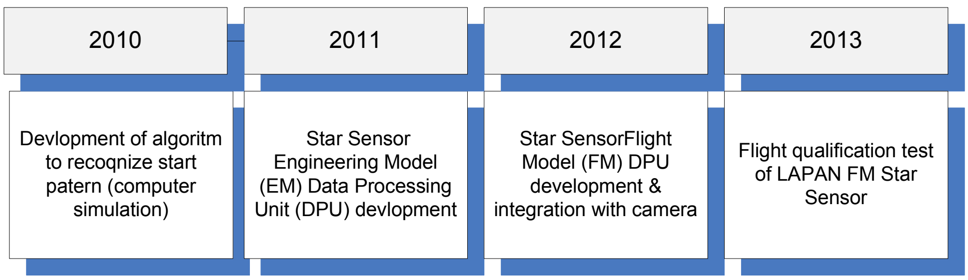

Figure 16. LAPAN's star sensor development steps

In 2010, nearest neighborhood star patern searching algoritm is selected to be implemented in LAPAN's star sensor PC model. The method detect the patern of stars near the brightest star captured by camera. The patern is then compared to the star catalog, that have been modified to ease the search. Test were done by capturing real star image using Kappa CCD camera that was specially design to extract coordinates from its 30 brightest pixels in the image. Test result using 16 mm lens show that the accuracy of the technique is under 1 arc min, which is sufficient for star sensor [ref Saifudin 2010].

In 2011 the developed algoritm was implemented in ARM7 microcontroller, as EM DPU. The limited computational power of the microcontroller, was compensated by increasing the code efficiency. As in 2010, test were done using real star image.

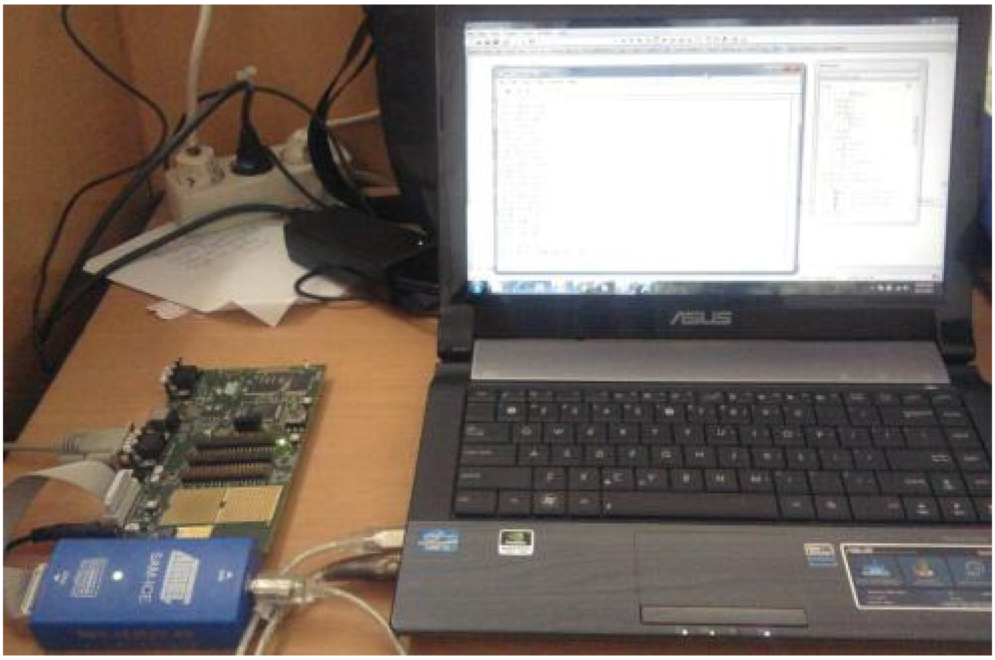

Figure 17. Testing the ARM 7 EM DPU

The improvement in star searching process, among others, is done by modifying the star catalog. The catalog is reduced 100 main stars (brightest) with 4000 of their nearest stars. The minimum brightness level is chosen on the lowest magnitude that the camera can detect, and differentiate them from hotspot (damaged pixel).

In 2012, the 1st production of LAPAN Star Sensor Flight Model (FM) was done, i.e. the electronics pacakaging of the DPU is made, and the star sensor baffle is integrated with the lens and camera (see figure 18).

FOV	31^{o} x 23^{o}
Focal Length	16 mm
Sensor size/pixel size	1040 x 1392 px / 6,45 µm
Power	12 VDC (nom.)
Baudrate	115200
DPU (1st batch)	ARM7 32-bit; 32 Kbytes SDRAM; 512 NAND Flash
Berat	1,55 Kg

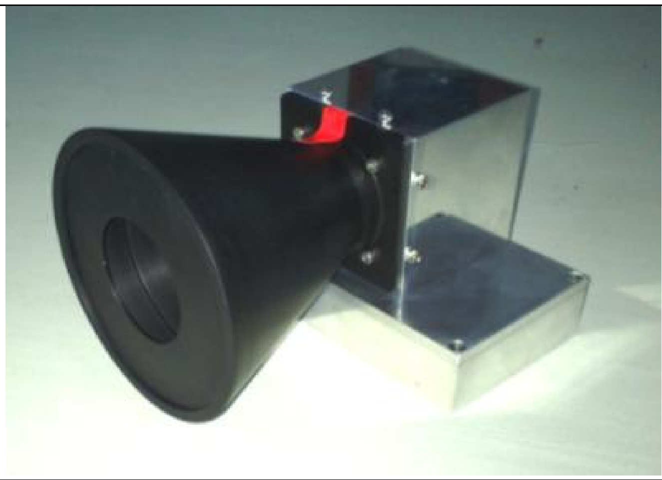

Figure 18. LAPAN star sensor 1st prototype

The flight qualification test planned for the star sensor in 2013 is thermal test, vibration test, and functional test. In order to intensify the functional test, star sensor simulator is developed. At the moment, star sensor functional test were done using real stars (at night). Since the development facility is in Bogor, which is one of the most couldy area in Indonesia, the success rate of the test (compared to its the attemps) is very litte. The schematic of the simulator is shown in figure 19.

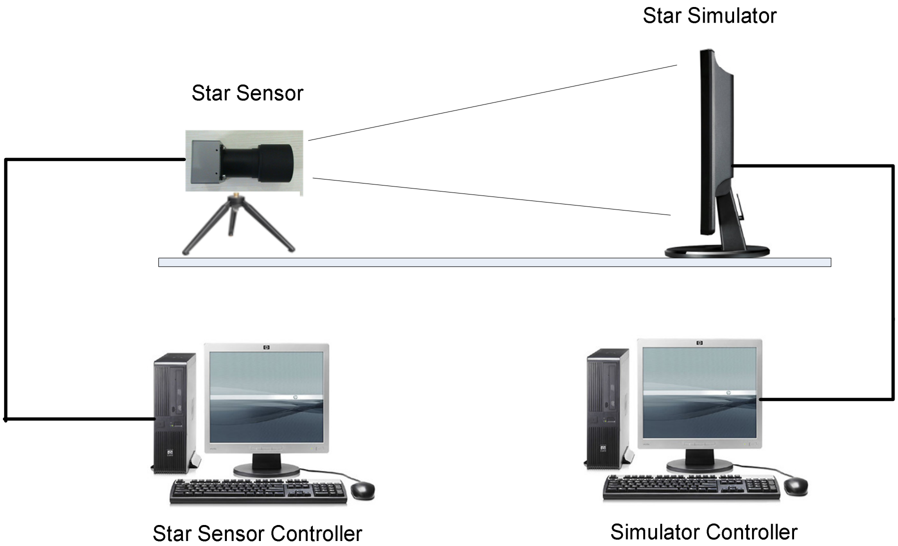

Figure 19. Scematic of LAPAN star sensor simulator

CONCLUSIONS & FURTHER WORKS

The development of microsatellite bus subsystem has been done in LAPAN. The subsystem being developed are satellite main computer or PCDH, and reaction wheel, star sensor. The development is aimed to support LAPAN's satellite program in the future.

Based on the progress of LAPAN's PCDH, reaction wheels, and star sensor development, further works planned for the next 4 years are :

	2014	2015	2016	2016
PCDH	Flight qualification test	AIT on LAPAN-A4	AIT on LAPAN-A4	In-orbit test on LAPAN-A4
Reaction wheel	Flight qualification test; Development of control modes	AIT on LAPAN-A4	AIT on LAPAN-A4	In-orbit test on LAPAN-A4
Star sensor	AIT on LAPAN-IPB	In-orbit test on LAPAN-IPB	AIT on LAPAN-A4	In-orbit test on LAPAN-A4

LAPAN-A4 is LAPAN's 4th micro-satellite, which assembly, integrated and test (AIT) is planned to start in 2015 and to be finished in 2016. The plan for satellite mission is repeating the mission of LAPAN-IPB, with payload developed by LAPAN. In addition to that, the satellite will fly several bus components developed by LAPAN as for in-orbit qualification test (in redundant).

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