Video Camera System on LAPAN-TUBSAT Micro-Satellite

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Abstract

The paper discuss about the payload of micro satellite LAPAN-TUBSAT, which is a high and low resolution video camera, as the satellite is to serve a surveillance mission. The discussion includes the brief description about the satellite, the specification the camera and optical system, their design implementation on LAPAN-TUBSAT. The discussion includes the payload system design and its ground test.

1 Introduction

LAPAN-TUBSAT is the first micro-satellite of Indonesian National Institute for Aeronautics & Space (LAPAN). It is a cooperation project between Lembaga Penerbangan dan Antariksa Nasional of Indonesia and Institut für Luft- und Raumfahrt of TU Berlin, Germany. The satellite is developed using the experience gained in TU Berlin's previous surveillance microsatellite, i.e. MAROC-TUBSAT and DLR-TUBSAT.

The satellite configuration is divided in two shelves, the upper shelf and the lower shelf. This design is made to provide maximum access to the component while harnessing and testing. The shelves are described in Figure 1. The cover of the lower shelf would be attached to the launch vehicle's separation ring. The lower shelf contains the attitude control system (3 fiber optic laser rate-gyros and 3 reaction wheels), one telemetry-and-telecommand (TTC) system, a payload camera with its 1000 mm lenses and S-band transmission system. The upper lower shelf contain the battery unit, power control and data handling system (PCDH), another payload camera with its 50 mm lenses and an air coil. In addition to that, two more air coils (placed orthogonally) occupy some space on the lower and upper shelf.

The power generator in the satellite is 4 Silicium solar panels, with the dimension of 432x243 mm. Each panel has 34 cell in series, which will provide maximum power of 14 W. The power storage system in the satellite consists of 5 NiH_2 batteries, configured in series. The batteries would provide nominal voltage of 12.5 V and have 8 Ah capacities.

There are two identical TTC systems in the satellite for redundancy purposes. The system used the frequency of 437.325 MHz, with FFSK modulation for up-link and down-link (half duplex). The communication data rate is 1200 bps and the hardware RF output is 3.5 W. The half dipole antennas of the system are placed orthogonally to guarantee link budget at any attitude.

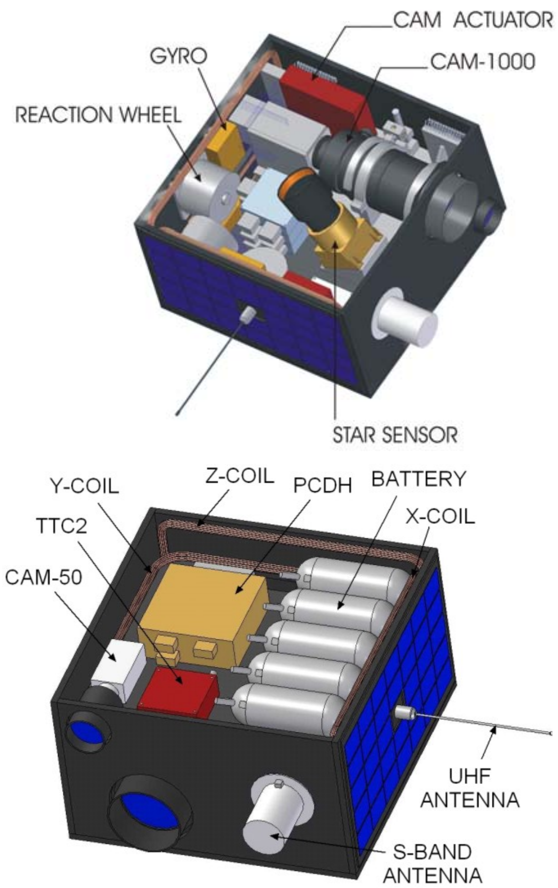

Figure 1: LAPAN-TUBSAT lower and upper shelves

The attitude control strategy of LAPAN-TUBSAT is based on the angular momentum management concept. Therefore, the attitude control system consist of 3 fiber optic laser rate-gyros (with <6 ^{o}/hr bias at stabilized temperature) to sense the rotation rate, 4 solar panel and 2 single cell son sensor to obtain satellite attitude, 3 air coil magneto-torquers (maximum of $1.2x10^{-4}$ Nm torque) to generate/deplete angular momentum, and 3 reaction wheels (max wheel speed 5000 rpm and the inertia of 0.00088 $kg.m^2$) to transfer angular momentum inside the satellite.

The payload video transmission system is used to transfer the video in PAL standard format (CCIR standard) to the ground station. The system used the frequency of 2220 MHz and FM video modulation. The transmitter has 5 W RF output, and the helix antenna has the beam-width of 70^o.

The dimensions of the satellite, excluding its antennas, are 450 x 450 x 275 mm and its weight is 54.7 kg. Therefore, LAPAN-TUBSAT envelope is compatible for piggyback ride constraint.

The mission of the satellite is environmental monitoring. Therefore, the satellite carry high-resolution video camera and active attitude control system to ensure its camera pointing. The satellite is placed by PSLV-C7 on January 10th, 2007, in sun-synchronous orbit of 635 km height. Such orbit will make the satellite pass Indonesian territory maximum 3 times during the day and 3 times during the night as described in Figure 3.

There are two mission strategies of LAPAN-TUBSAT in taking images, the first is the scanning mode and the second is hovering mode. In the scanning mode, the attitude of the satellite is controlled so that the camera side will face the Earth with particular angle with respect to Earth surface. In the hovering mode, the satellite attitude is controlled interactively (real time) by means of feedback from video streaming sent by the satellite. Therefore, the camera can be pointed to particular object that the operator would like to see.

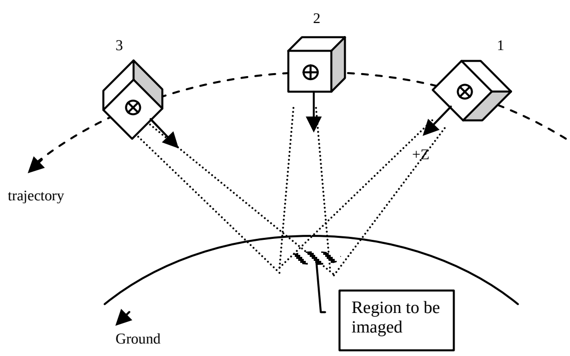

Figure 2: Target locking scenario

2 High Resolution Camera

2.1 DXC-990P dan Nikon f11/1000

The video camera used in LAPAN-TUBSAT is not the camera that is specially made for space application. The camera is designed for monitoring in medical application and product inspection in industry. The camera is Sony Color Video Camera DXC-990P. The camera has 3 CCD chips and prisms which function as optical filter (to split the light according its color. The incoming light is split into color: red, green, and blue, which then fell into the three CCD. Therefore, each CCD would have full resolution. In addition to the argument about resolution, the choice of using camera with beam splitter is to avoid the degradation (due to space radiation) that could happen in the organic color coating usually applied on CCD pixel (to create RGB input). The radiation damage on CCD color coating can be reduced by applying quartz optic on the lens. However, placing quartz lenses in front off-the-self long focal length lens could create another optical problem. Another advantage of using beam splitter is on the simplicity of image processing.

Each of the camera's CCD has 752x582 pixels. Each pixel has the size of 7x7 micron.

The choice of the camera is also because the CCD uses Exwave HAD technology. The technology is made especially for surveillance camera, which often exposed to widely varying illumination intensity. Experience from DLR-TUBSAT indicate the needs of such feature since the camera will scan the horizon and the area that partially cloudy. The sensitivity of CCD is defined by the tolerance of 'smear' or the light leaking to neighboring pixels (due to reflection) and therefore affecting the reading of the pixel. Increasing the level of noise filter could help remedy the situation but will reduce the sensitivity. The new method applying micro-lens on each pixel so that all the light directed to gap area (between pixels) can be diffracted to the effective sensor area and not polluting the neighboring pixels.

Nikon photographic lens with focal length of 1000 mm and f number 11 is placed on the camera. The lens is Casegrain type. The choice of the lens is based on DLR-TUBSAT experience and the maximum dimension can be accommodated in the satellite.

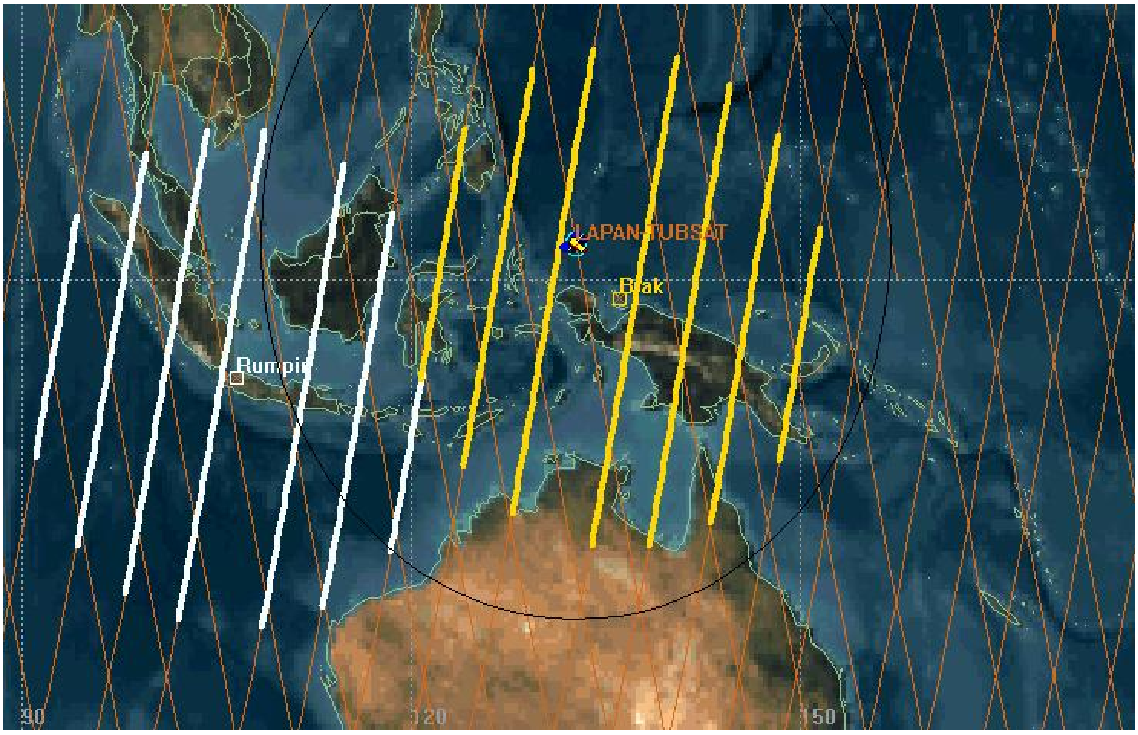

Figure 3: Typical 5 days passes of LAPAN-TUBSAT over Indonesia,
and the coverage of Rumpin and Biak G/S

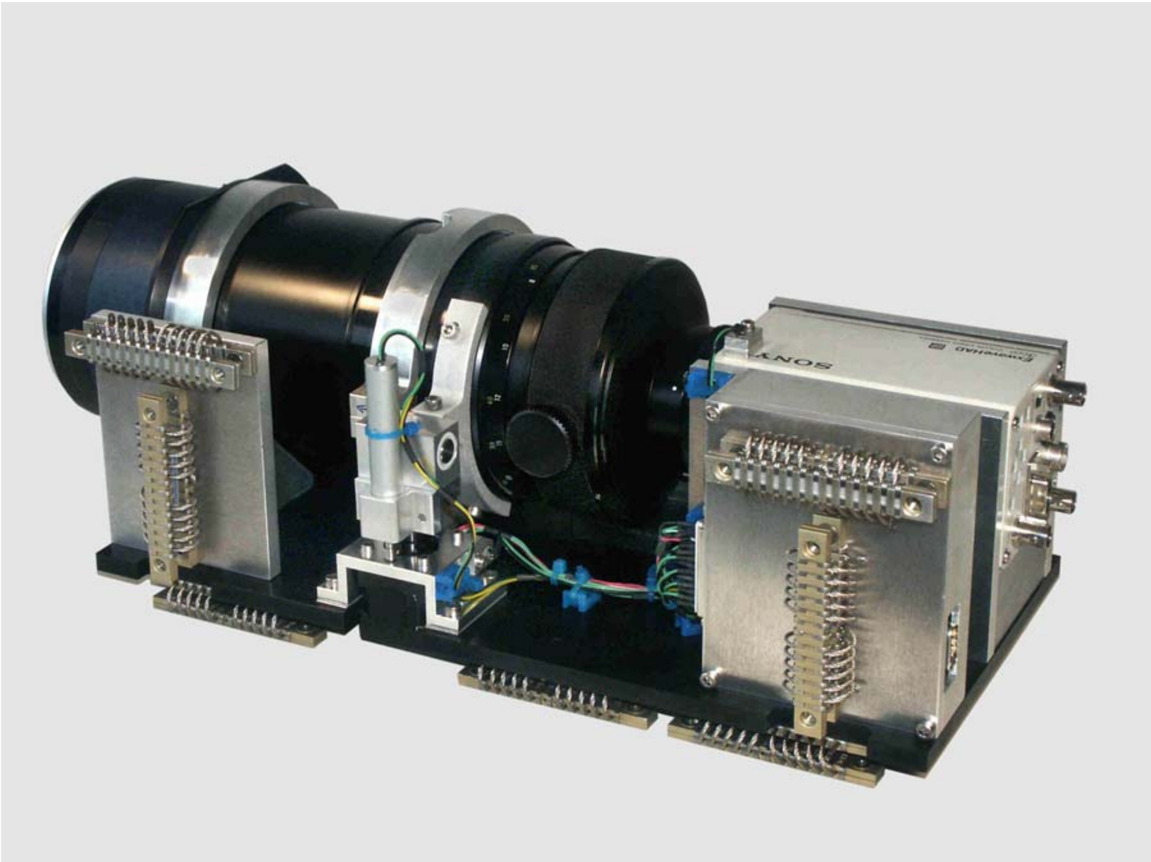

Figure 4: The 1000 mm lens, lens actuator, camera, and shock damping mechanism

The camera has scanning frequency of 15.625 KHz in horizontal direction and 50 Hz in vertical so that it can produce 50 frames of image per second. The camera's output format PAL video, which will produce 850 lines on TV.

The 'all auto' mode is selected for the default operation of the camera. This means that the camera's computer will control the 'gain', 'white balance', and 'shutter speed' automatically to obtain optimal images. If, for some condition, the parameters above need to be adjusted manually, the command can be given via LAPAN-TUBSAT's main computer. The maximum shutter speed of the camera is 0.000001 second, so that the camera will be able to compensate blooming or overexposure when taking images in cloudy area (that reflect the sunlight). During the operation, experiment will be done to see whether the optimal shutter speed can be selected as function of illumination and satellite speed.

2.2 Resolution

In the payload user's point of view, the resolution is defined as the ability to distinguish detail of the object on the surface of the Earth when the camera is pointed nadir.

Based on the pixel size, the resolution means the dimension of the area captured in one pixel of the CCD. Using geometric analysis[1)], it was found that with 1000 m lens and at distance of 680 km from object, 7x7 micron pixel will represent 5x5 m area. It also means that 5.55 x 4.76 mm chip would give image frame from 3.8 x 3.2 km area on the ground.

Based on the light diffraction theory[1)], a point of light will not be seen as a point of light in the focal plane but seen as several concentric circles in which the intensity gradually reduced in radial direction. Therefore, the resolution in this theory is defined as the smallest diameter of the point of light that can be form on CCD plane. The diffraction characteristic is a function of the wavelength. The light to be captured by LAPAN-TUBSAT's camera has the wavelength of 0.4-0.7 μm (visible light spectrum). Based on the diffraction theory, the diffraction theory, considering that LAPAN-TUBSAT camera uses a lens with f/D = 11, the smallest diameter for red light (λ = 630 nm) is 16,9 μm, and for blue light (λ = 500 nm) is 13,4 μm.

Meanwhile, LAPAN-TUBSAT's CCD pixel size is 7x7 μm, so that, the point of light formed on CCD will fall into 4 pixels which cover the area of 14x14 μm. Therefore, based on this theory, the image resolution of LAPAN-TUBSAT is limited more by the diameter of the lens then the pixel size, which means is about 10x10 m size on the ground.

3 Design Implementation

3.1 Space Qualification

Because LAPAN-TUBSAT camera is not designed for space application, several modification and supporting system are applied so that the system could endure the harsh environment during and in orbit.

The electrolyte capacitor in the camera is replaced by tantalum to prevent outgassing in vacuum. The test in vacuum chamber (0.0001 Bar) shows that camera work perfectly in vacuum. In addition to that, additional soldering is applied in the joins that hold the prism to increase the stiffness and strength of the joins to endure the launch's vibration.

The power consumption of the camera is 7.6 Watt, which is suitable for power limitation of LAPAN-TUBSAT. A 12 V regulator is assigned for the camera since the satellite bus' voltage is 12-14 V, depending on the status of the battery charge.

The operating temperature guaranteed by the manufacturer of the camera is -5 to 45^{o}C. The structure of LAPAN-TUBSAT is designed to have excellent conductivity and heat capacity (based on TUBSAT heritage). It is mainly consisted of black anodized aluminum plate of 10 mm thick. The experience on TUBSAT shows that the temperature of the satellite structure is always between -10 to 10 ^{o}C. Similar thing is expected to happen in LAPAN-TUBSAT. Therefore, in the qualification test, the camera is operated in the environment of -20 ^{o}C. The result of the test shows that in such condition, the camera function very well.

A platform consists of steel spring (braided wire type) and aluminum plates supported LAPAN-TUBSAT high-resolution camera system. The purpose of the platform is to protect the brittle optics from the vibration and shock during the satellite transportation and launch.

Since the manufacture of the camera only provide 1 mounting bolt on the camera, additional aluminum holder plates is used to encircle the 70 x 72 x 123.5 mm camera. In addition as mounting system, the plates also function as heat conductor and increase the inertia property of the camera which only weight 630 g. The weight of the overall system as described in figure 1 is 7.8 kg.

3.2 Focus control

The quality (sharpness) of the image taken by the camera depends on the accuracy of the concentrated light rays from the object (from the ground/680 km distance) in falling to the CCD plane. Meaning that the focus of the lens has to be ensured to fell on the CCD, which is a function of the distance from the object. Meanwhile, the operating temperature in space varied drastically. Inside LAPAN-TUBSAT it is estimated to fluctuate between -20 to 20^{o}C. Such variation would affect the casing of the 1000 mm lens. The casing is made from metallic components, which has relatively large thermal expansion coefficient. In addition to that, the Casegrain configuration of the lens made one unit length change in the axial direction of the lens will create 3 unit length changes in the location of the lens' focus. Because of that, LAPAN-TUBSAT has mechanical actuator to control the lens focus according to the temperature of the lens.

The mechanical actuator consisted of motor servo, electronic circuit to control the servo, position and temperature sensors and movement translation mechanism. The servo control electronics uses microcontroller similar to LAPAN-TUBSAT main computer. The function of the electronics is to control the power to the servo and get data from position sensors and 4 temperature sensors placed on the lens and camera. The position and temperature information will be used as guidance for direction to adjust the lens' focus. The movement translation mechanism is used for to convert the linier movement of the servo to rotation+forward/backward movement on the lens (screw type focus adjusting system). To anticipate vacuum condition, the grease in the servo's bearing and potentiometer is replaced with grease typically used in vacuum compressor (fluorinated fomblin) to prevent outgassing. Meanwhile in the translation mechanism, Teflon bushing is used.

The focus control can 'move' the lens' casing up to 0.6 mm, which mean that the lens focus can be adjusted by 3.6 mm. This made the focus at the object of 680 km from the lens can be adjusted to fall on the CCD in temperature range of -50 to 50^{o}C.

The command to operate the focus control transmitted via LAPAN-TUBSAT main computer, using software developed by TU Berlin. The mechatronic system has endured tests in various temperatures setting as well as vacuum and shown that the system works very well. The system has also endured vibration test as according to the launch vehicle specification.

3.3 Low-resolution Camera

Operating the high resolution camera, especially to find certain location on the ground interactively, will not be easy if only rely on 3.8 x 3.2 km image. In such size, the geographical characters such as coastline and mountain that can be used as landmark will be hard to be seen. Therefore, LAPAN-TUBSAT payload is complemented with low-resolution camera as viewfinder (to search particular location). Such step will be done before zooming by using the high-resolution camera.

Video camera used for the application is KAPPA CF 142. The camera has single CCD with 752x582 pixel area. The CCD is color coated for RGB and also uses Exview HAD technology. A 50 mm lens is placed on the camera to produce image with 81 km width with 200 m resolution. The camera operation also uses all auto modes (for gain, white balance and shutter speed). The maximum shutter speed is 0.000001 second and the camera output is in PAL format (480 horizontal picture line). The camera consumes 3 Watts power at 12 V, so that it is connected to the same voltage regulator as the high-resolution camera.

Figure 5: The 50 mm lens, Kappa camera, extra baffle and mounting system

4 Resolution Test

The resolution test is done after ensuring the image transmission via RF is checked-out. The test set-up for LAPAN-TUBSAT payload is as described in Figure 3. The purpose of the test is to check whether the high-resolution camera will produce image at 10 m from 680 km distance.

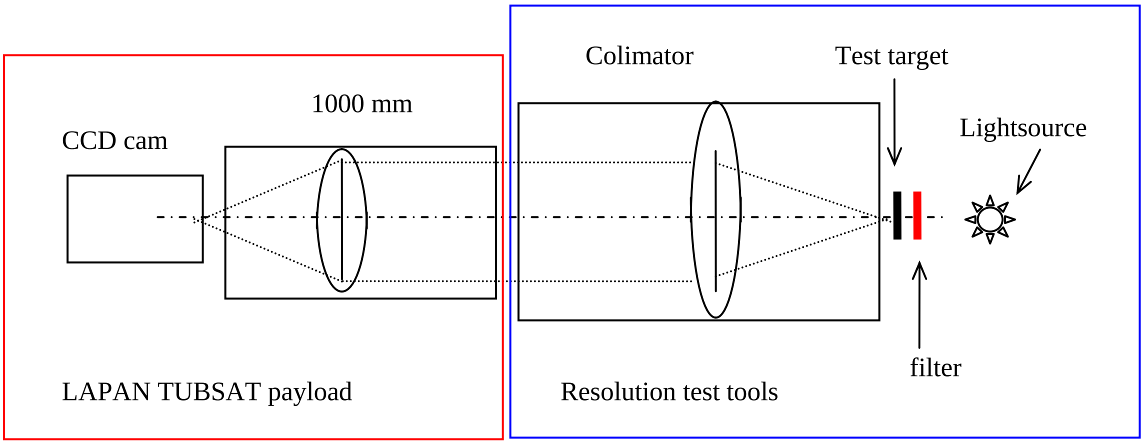

Figure 5: Schematic of the resolution test

The test target used in the test is the microscope calibration specimen, i.e. 1951 USAF negative resolution target from Edmund. The target is placed on the focal plane of the collimator, which will simulate object at near infinity relative to focal length of the lens. The collimator used belongs to the Department of Physic of TU Berlin. It has a focal length of 2500 mm. A green filter is used in front of the specimen so that the 16 mm wavelength will arrive at LAPAN-TUBSAT payload.

The image from the transmitted video showed the smallest line can be observed is from the group 3 elements 6 of the test target. This means a line of 70 mm thick on the specimen. Theoretically, using collimator with focal length of 2500 mm and green filter, the thinnest line that should be observed by LAPAN-TUBSAT payload is 40 mm.

The different in the theory and test result may be caused by several factors. It is unlikely that the video conversion from digital to video analog (PAL) contribute in the degradation of resolution. The more probable explanation is the accuracy of the accuracy of the test target position on the collimator and the accuracy of the CCD on the focus of 1000 mm lens.

In the image formation, the tolerance of focus sharpness defines by the Depth of Field theory. The theory defines the limit in which the image of the object can be formed sharply based on Gauss' lens theory[8)].

The theory yield that if the object located at infinity, the image will exactly fall in the focus. In the case of LAPAN-TUBSAT, which its lens' focal length is 1000 mm and the object at about 700 km, the images shall be formed at 1000.001 mm from the lens or 1 micron behind the focal plane. If the error is still within depth of field then the image will be seen sharp. Using collimator with focal length of 2500 mm, the situation is reversed. If the location of the test target misses by 0,005 mm from the collimator's focus, the image will be seen as if it comes from 1250 km distance from LAPAN-TUBSAT's lens. When the light from the collimator, as mentioned above, entering LAPAN-TUBSAT payload, the image will fall at 0.8 micron behind the lens. Meanwhile, the existing set-up, i.e. the focus control mechanism on 1000 mm lens and the test target holder in the collimator (manually adjusted) has the accuracy higher than 70 micron.

Therefore, it is most probable that the light fell outside the limit of the lens' depth of field (which is a function of, among others, the lens' aperture[7)]). If the above mentioned phenomena happen, then 40 micron thick line that should be seen clearly according to calculation is shown blurry, and only thicker line is shown to be sharp.

Further research needs to be done on the subject to check the validity of the resolution test. However, the satellite development time limit, which initially will be launched on September 2006 or 1.5 years after component procurement, did not permit such effort to be done.

5 Conclusions

1. The system that made an off-the-shelf camera become a flight qualified satellite payload has been developed.
2. According to theoretical calculation, the best resolution of LAPAN-TUBSAT camera from 680 km orbit is 10 m.
3. The limited ground performed shows that the best resolution of LAPAN-TUBSAT from 680 km orbit is 18 m.

4. The cause of the difference between the theory and test can not yet be determined, even though probable cause is identified.
5. Further research on LAPAN-TUBSAT camera is proposed to be done using the similar camera and lens belong to the Center for Space Electronics, LAPAN.

Acknowledgement

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