Observation of the LED signal from FITSAT-1

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We are developing a satellite named FITSAT-1. This satellite has two missions. One is to transmit pictures that were taken by the camera in the satellite using the micro wave of 5.8 [GHz]. The other is to demonstrate the feasibility of the optical communication by use of LEDs mounted on the satellite. The front side of the satellite is fitted by green LEDs, which have high visibility. The electric power of green LEDs is 20 [W] in average. The light signals are modulated at the rate of 10 [Hz]. In order to increase the signal to noise ratio (S/N), each pulse is modulated again at the rate of 5 [kHz]. The main causes of the noise are the stray light from the night sky and the dark current of the photomultiplier (PM). The S/N of the light signals is increased by using an optical band path filter. The electrical band path filter having the Q value of about 50 selects the components of 5 [kHz] from the electrical signals of PM in order to increase the S/N furthermore.

Key Words: LED, S/N, satellite, optical communication, photomultiplier

1. Introduction

In recent years, LEDs have made a great progress and have been attracting attention as electric power saving light source. The LED does not interfere with radio communication and does not affects the precision equipments in hospitals or aircrafts.

In 2005, the satellite called “Kirari” succeeded in the laser optical communication between the satellite and the ground. In this case it is necessary to control the attitude of the satellite because of the high directivity of the laser. In case of the LED, the directivity is not so high as that of the laser. We think the optical communication by LEDs is suitable for a small satellite because the attitude control is difficult in this case. When the propagation distance is long, the LED light is spread across and becomes very weak on the ground because the directivity is low.

Fig. 1. Overview of FITSAT-1.

We has been developed the small satellite (FITSAT-1) that is going to be released from Japanese work space of the International Space Station (ISS). The purpose of this study is the demonstration of the low-light-level optical communication by the LED between the satellite and the ground.

2. FITSAT-1

FITSAT-1 (nickname “NIWAKA”) is the small cubic satellite of 10 [cm] square. Fig.1 shows an overview of FITSAT-1. The orbital altitude is about 400 [km], the period is 90 minutes and the lifetime is about 100 days. The orbit is almost the same as that of ISS just after the releasing. It has two missions. The main mission is “the high-speed transmission of pictures by microwave of 5.8 [GHz]” and the sub mission is “the demonstration experiment of low-light-level optical communication by the LED between FITSAT-1 and the ground”.

3. Experimental system

An overview of the experimental system is shown in Fig.2. The cloudless and dark sky is the necessary condition for observation of the LED light. Under this condition, opportunities of the observation are limited to be few days in the life-time of FITSAT-1. In order to solve this problem, the observe system was designed to be mobile to make it possible to choose the observation point from many candidates.

3.1. LED lighting system

3.1.1. Selection of the LED

The arrangement of green LEDs on FITSAT-1 is shown in Fig.3. In the optical communication between the satellite and the ground, LED lights become very weak on the ground because the propagation distance of LED lights is very long. Therefore, it is necessary to select of high-brightness and electric power saving LEDs. In this study, after comparing the performance of variety of LEDs, we have chosen 3[W] high-power LEDs (Seoul Semiconductor). The green LED (wavelength: 526 [nm]) with excellent sensitivity of vision was selected. 50 LEDs were placed in to 2 parallel x 25 series. The total power is 20 [W] in average.

3.1.2. Modulation of the LED signal

Because the optical communication by LEDs is easily affected by the stray light in the night sky, it is necessary to select the suitable modulation method to be free from this influence. In this study, the LED signal was doubly modulated at the frequency of 10 [Hz] and 5 [kHz]. The duty ratio of 10 [Hz] is 30 [%] and that of 5 [kHz] is also 30 [%].

Modulation rate of 10 [Hz] and the duty ratio of 30 [%] was chosen to obtain high visibility of human eyes. Fig.4 shows the temporal construction of the LED signal. To calculate the frequency spectrum of the LED signal, Fourier analysis of the LED signal was performed using MATLAB. Fig.5 shows the results of Fourier analysis. The band width was found to be about 0.3 [kHz].

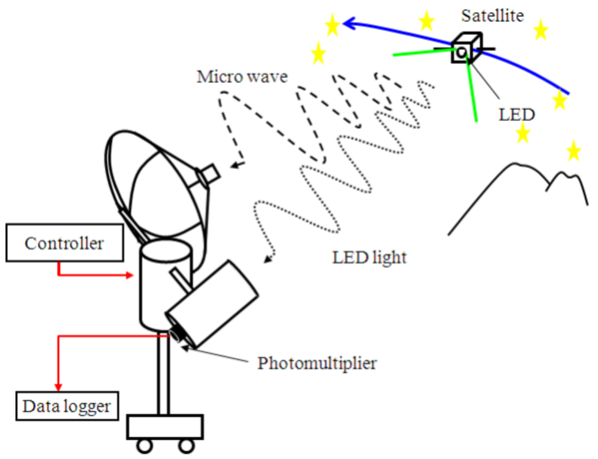

Fig. 2. Overview of the experimental system.

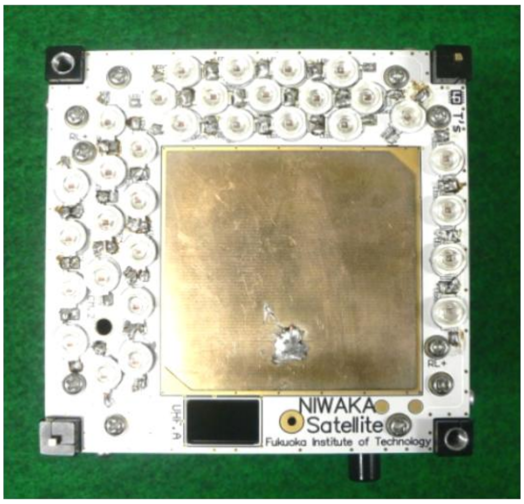

Fig. 3. Front panel of FITSAT-1 equipped with LEDs.

3.2. Light receiving system

The experiment setup for receiving light is shown in Fig.6. The LED light is collected using a telescope with the aperture of 250 [mm] (KENKO, Sky Explorer SE250N CR). We used the optical band path filter (wavelength: 520 [nm], bandwidth: 30 [nm]) to decrease the stray light from the night sky. The emission spectrum of the LED and the transmitting band width are shown in Fig.7. It can be seen that about 70 [%] of LED light can transmit though the band path filter. We used a photomultiplier (PM) (HAMAMATSU, H6410) with large active diameter of 46 [mm] to increase the observation view angle.

3.3. Magnitude of FITSAT-1

The following is the calculation of the irradiation power density of 5^{th} magnitude star on the ground. The absolute magnitude (The magnitude observed on the Earth when the star was placed in the distance of 32.6 light-years away from the Earth) of the sun is 5^{th} grade. If the sun was placed on the

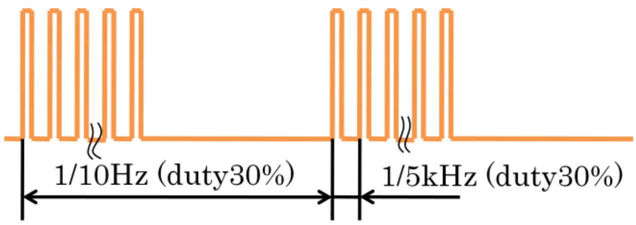

Fig. 4. Temporal construction of the LED signal.

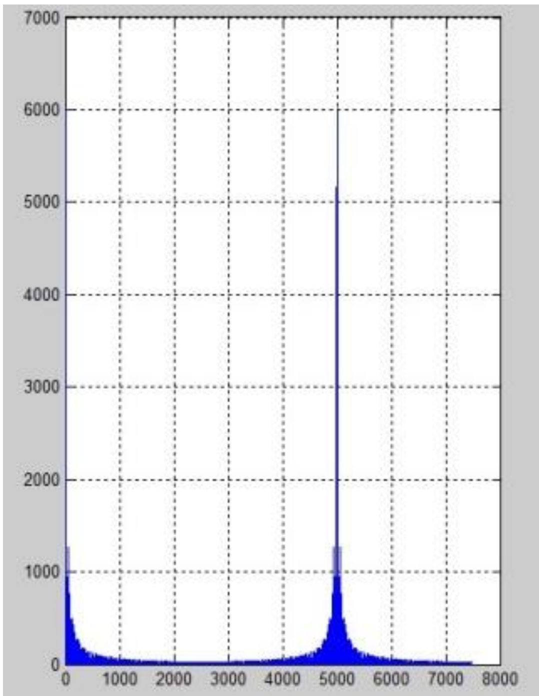

Fig. 5. Fourier analysis of the LED signal.

point 32.6 light-years away, the intensity of light is weakened by the ratio of

$$A = \left(\frac{\textit{The distance between the sun and the Earth}}{\textit{The distance of 32.6 light years}}\right)^2$$
$$= 2.35 \times 10^{-13}.$$

The irradiation power density of sunlight measured on the ground is 1.35 x 10^3 [W/m^2]. The transmission of visible light through the air is about 80 [%]. The ratio of the visible light is about 47 [%] of whole radiation. By using these factors, the visible irradiation power density *B* on the ground of the sun is calculated to be

$$B = 1.35 \times 10^3 [W/m^2] \times 0.8 \times 0.47 = 5.1 \times 10^2 [W/m^2].$$

Therefore, the irradiation power density of 5th magnitude star *C* is calculated to be

$$C = \mathrm{AB} = 1.2 \times 10^{-10} [\mathrm{W/m^2}]$$

The number of LED is 50, the average electrical power is about 20 [W] and the beam divergence angle is about 120 [deg]. Assuming that conversion efficiency of the LED from the electric power to the optical power is 20 [%] and the transmittance of the atmosphere for the green light is 90 [%],

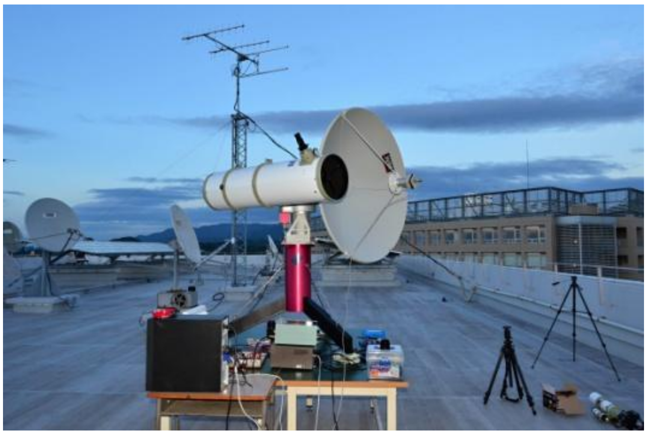

Fig. 6. Detection system of the microwave and optical signals from FITSAT-1.

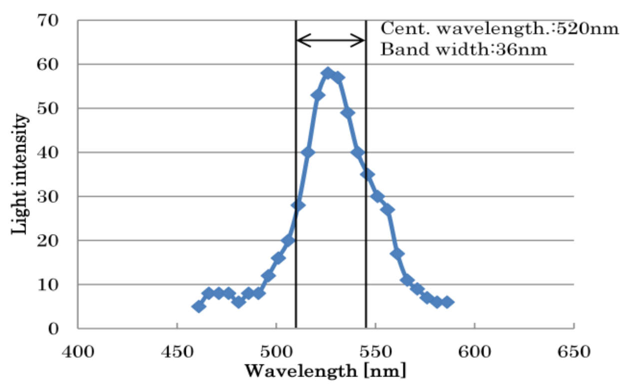

Fig. 7. Wavelength spectrum of the green LED with the band width of the optical band path filter.

the power of the LED light on the ground is calculated to be about 3.6 [W]. The partial area S_p irradiated by the LED of the total sphere surface area with the radius of 400 [km] is calculated to be

$$S_p = \int_0^{\frac{\pi}{3}} 2\pi r^2 \sin\theta d\theta$$
$$= \pi r^2 = 5.03 \times 10^{11} [\mathrm{m^2}].$$

Assuming that LEDs light is uniformly spread in this area, irradiation power density on the ground is calculated to be 1.07 x 10^{-11} [W/m^2]. The increase of 2.5 [times] in the light intensity of the star corresponds to that of 1 grade in the magnitude of star. The grade of FITSAT-1 is calculated to be 8.1th magnitude.

4. Improvement in the S/N of the LED signal

As the light arrived at the ground is extremely weak, it is very important to improve the S/N of the LED signal, and we adopted the subcarrier pulse modulation method. We used the positive feedback band path amplifier in addition to the optical band path filter. The positive feedback band path filter circuit is shown in Fig.8. In order to measure the band path amplification characteristics, we use the 2 [mV] sinusoidal wave as input signal and measure the output signal voltage changing the frequency from 1 [kHz] to 10 [kHz]. The experimental result is shown in Fig.9, which shows a sharp

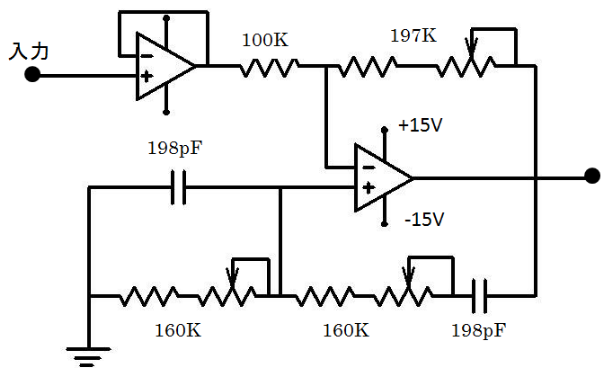

Fig. 8. Electronic circuit of the active band-path filter.

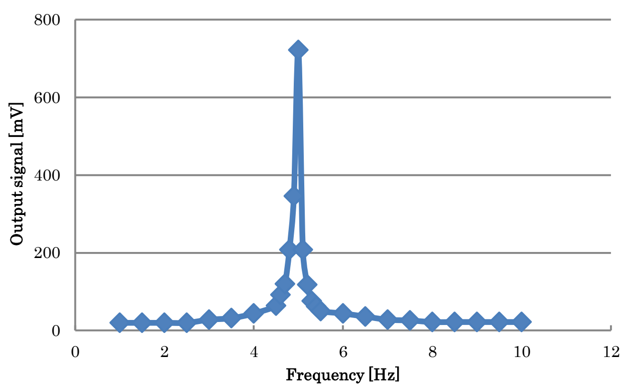

Fig. 9. Amplification characteristic of the sinusoidal wave of 2 [mV].

peak at 5 [kHz].

5. Optical communication experiment using a flight model (FM) on the ground

The optical communication experiment using FM was carried out between the beach in Fukuoka city and the rooftop of the eight stories building of FIT on July 17, 2012. The signal was transmitted from the beach and received at FIT by the telescope, and then the optical signal was transformed to electronic signal by PM. The electronic signal is stored using the Data logger (YOKOGAWA, DL850) after it was processed by the signal processor.
The optical band path filter was used to remove the stray light from illuminating lights in the town. The supply voltage of PM was 1.1 [kV]. This sensitivity is about 1 [%] of that for the rated value of 2 [kV]. In the experiment, the signal was received successfully and the measured data was shown in Fig.10. The upper trace is the LED signal without the band path amplification and the lower trace is the LED signal with the band path amplification. Horizontal full scale is 1 [s] and both vertical full scales are 30 [V].

It can be seen from Fig.10 that the S/N value of the signal could be remarkably increased after being processed by the band path amplification. We can see the remarkable improvement in the S/N of the LED signal by use of the band path amplifier in Fig.10.

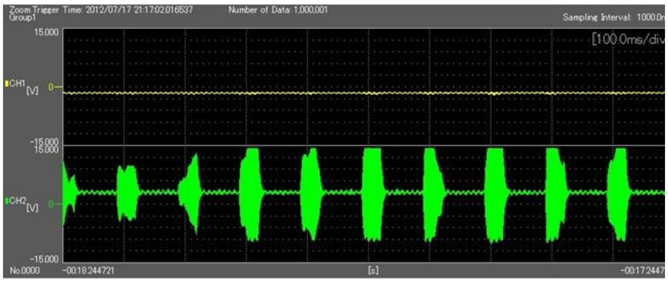

Fig. 10. Comparison of LED signals without (upper signal) and with (lower signal) the band path amplification. Horizontal full scale is 1 [s] and both vertical full scales are 30 [V].

6. Summary

We have developed a satellite named FITSAT-1. This satellite has two missions. One is to transmit pictures that were taken by the camera in the satellite using the micro wave of 5.8 [GHz]. The other is to demonstrate the feasibility of the optical communication by use of LEDs mounted on the satellite. LEDs are fitted on the front sides of the satellite. The front side is fitted by green LEDs, which have high visibility. The electric power of green LEDs is 20 [W] in average. The light signals are modulated at the rate of 10 [Hz]. In order to increase the S/N, each pulse is modulated again at the rate of 5 [kHz]. The main causes of the noise are the stray light from the night sky and the dark current of the photomultiplier (PM). The S/N of light signals is increased by using an optical band path filter. The electrical band path amplifier having the Q value of about 50 selects the components of 5 [kHz] from the electrical signals of PM in order to increase the S/N furthermore.

The optical communication experiment using FM was carried out between the beach 12 [km] away in Fukuoka city and the rooftop of the eight stories building of FIT, and we have succeeded in the improvement in increasing the S/N remarkably by use of the optical band path filter and the band path amplifier for the 5 [kHz] subcarrier signal.

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