AIPAdvances

Transmission of the LED light from the space to the ground

Y. Kawamura and T. Tanaka

Citation: AIP Advances **3**, 102110 (2013); doi: 10.1063/1.4824853
View online: http://dx.doi.org/10.1063/1.4824853
View Table of Contents: http://aipadvances.aip.org/resource/1/AAIDBI/v3/i10
Published by the AIP Publishing LLC.

AIP ADVANCES **3**, 102110 (2013)

Transmission of the LED light from the space to the ground

Y. Kawamura[1,a] and T. Tanaka[2]
[1]*Department of Intelligent Mechanical Engineering, Fukuoka Institute of Technology, 3-30-1 Wajirohigashi, Higashiku, Fukuoka, 811-0295, Japan*
[2]*Department of Information Engineering, Fukuoka Institute of Technology, 3-30-1, Wajirohigashi, Higashiku, Fukuoka, 811-0295, Japan*

(Received 3 April 2013; accepted 24 September 2013; published online 10 October 2013)

We report the first observation and the analysis of the LED light emission from the space to the ground. A small cube satellite mounted LEDs (Light Emitting Diodes) is released from the ISS (International Space Station). The power density of the LED emission of 4W on the ground is about 4×10^{-12} W/m^2 in average, which is equivalent to the star of the 8.5th grade in average. The frequencies of the macro pulses (10Hz) and the micro pulses (5kHz) of the LED signal, were correctly clarified using the Fourier analysis. As the optical communication experiment, the potentiality of the data transmission rate of more than 1 kbit/second was shown. [http://dx.doi.org/10.1063/1.4824853]

I. INTRODUCTION

We report the first emission of the artificial visible LED (Light Emitting Diodes) light in the space use and the observation and the analysis of them on the ground.

Recently, LEDs have been used in many fields, such as the illumination, traffic signal and a light source for the optical communication, and light intensity of LEDs has been increased abruptly. LEDs are by no means a revolutionary light source comparing to the filament bulbs and the fluorescence bulbs. The LED lights is considered to be a "quantum" light and essentially have the characteristics of high efficiency, fast response and long life time. They are considered to be the light source in the next generation. This is one of the reasons, why we have chosen the LEDs for the light source of our experiment.

We have developed a small cube satellite[1] named FITSAT-1[2,3] mounted with many high brightness LEDs and released it from the ISS (International Space Station) to illuminate them in the space. There have been another two planes to mount LEDs on a small satellite, one in Japan[4] and the other in Korea,[5] but they have not been realized until now. Scientific usage of an infrared laser (800nm) was reported for the inter-orbit optical communication.[6]

In this paper, we report the successful transmission of the visible LED light from the space to the ground and identification of them using Fourier analysis in order to demonstrate the first transmission of visible light from the space to the ground and consequently to demonstrate the feasibility of the optical communication between the cube satellite and the ground station.

II. FITSAT-1

Figure 1 shows a small cube satellite mounted high brightness LEDs (code name: FITSAT-1, nickname: "NIWAKA"), which was released from the ISS (International Space Station) on October 5th, 2012. It is a small cubic type satellite (10cm × 10cm × 10cm, 1.3 kg). The wavelength, the total power and the light divergence angle of the LEDs are 520 nm, about 4W in average (macro pulse

[a](kawamura@fit.ac.jp)

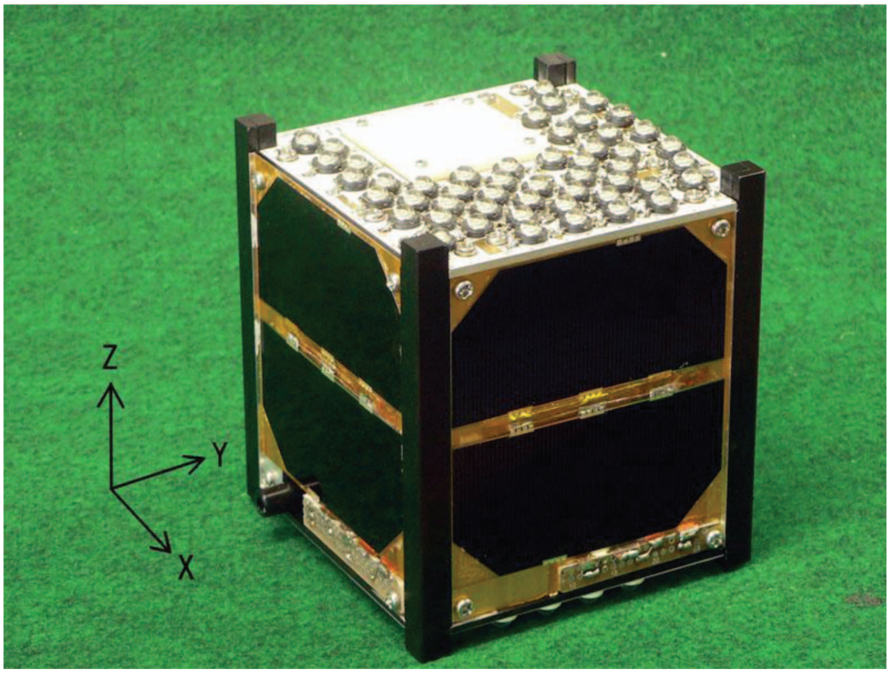


FIG. 1. A small cube satellite (code name: FITSAT-1, nickname: "NIWAKA"). 50 high brightness LEDs are installed on the top surface (*z* surface).

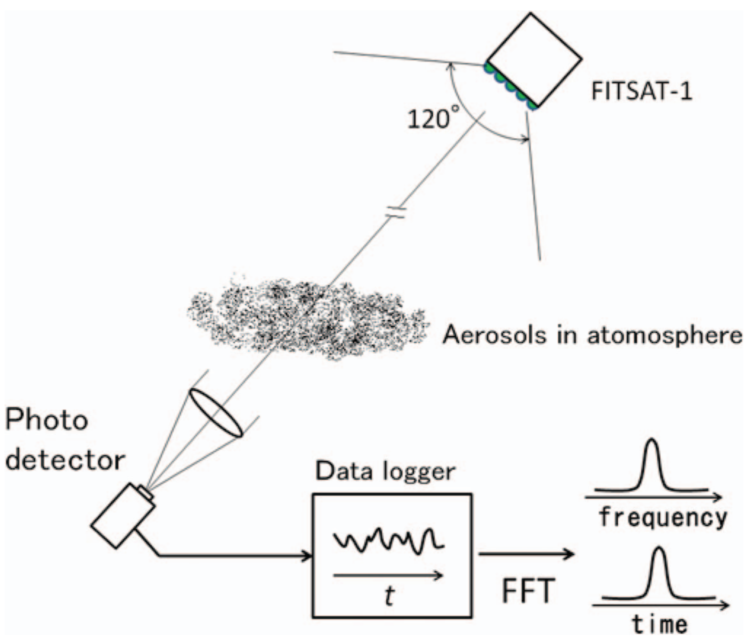


FIG. 2. Configuration for detection and identification system of the LED light signal using Fourier analysis.

power: 13W in average, micro pulse power: 44W) and about 120 degrees, respectively. The total number of LEDs is 50.

III. EXPERIMENT

Figure 2 shows the experimental configuration for the emission and detection of the LED light from the space. The orbital altitude of the satellite is about 400km. The attitude of the satellite is

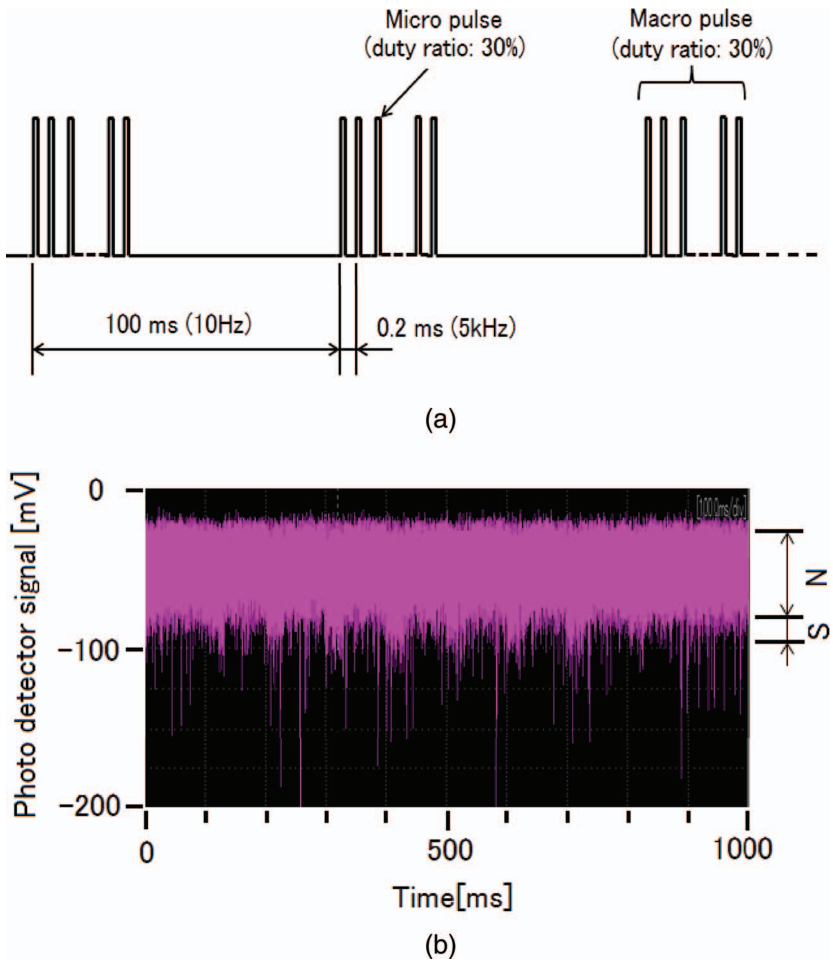


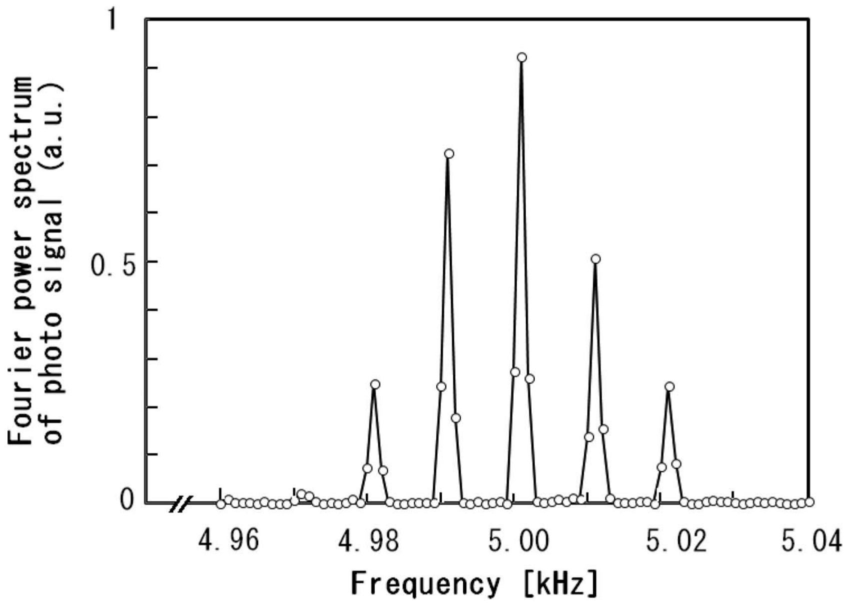
FIG. 3. A. Temporal configuration of the LED emission signal. The signal consists of the continuing macro pulse train of 10 Hz (duty ratio: 30 %), and each macro pulse is modulated at 5 kHz and consists of 150 micro pulses. Whole length of the pulse train is 120 second. B. Output signal of the photo detector recorded by the data logger. (S: signal, N: noise) The data were taken at 1:10 on Dec. 14th (Japan standard time) in Yufu city, Fukuoka prefecture, Japan.

passively controlled making use of the function of the magnetic compass induced by a permanent magnet in the satellite and the geomagnetism. The axis of the magnetization of the magnet is parallel to the axis of the emission of the LEDs. Therefore, at the point of observation (Fukuoka, Japan), the axis of emission is inclined about 47 degrees from the horizontal surface, which is the angle of geomagnetic inclination at this point.

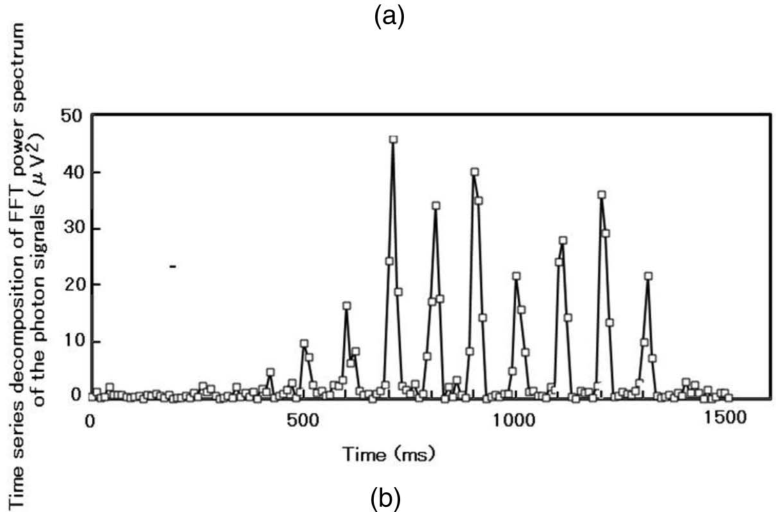
Due to the wide range of the divergence angle of LEDs, the light is spread over the area shaped like an ellipse with the minor diameter of more than 1000 km on the ground. The power density of the LED emission on the ground is estimated to be about 4×10^{-12} W/m^2 in average. It is equivalent to the star of about 8.5$^{\text{th}}$ magnitude.

The light signal was collected by a telescope with the aperture diameter of 0.25m, and it was detected by a photo detector (photomultiplier HAMAMATU, R329-02) after passing through an optical band pass filter (central wave length: 520nm, band width: 20 nm).[7,8] The optical sight angle, which is determined by the focal length of the telescope (1.2m) and the aperture size of the photo detector (0.02m), is calculated to be 0.17 radian.

As shown in Fig. 3A, the LED emission signal consists of the pulse train of 10Hz (duty ratio: 30 %), and each macro pulse is modulated at 5kHz. Flashing frequency of 10Hz was chosen to increase the visibility for the human eyes.[9] The whole length of the pulse train is 120 second.



(a)



(b)

FIG. 4. A. FFT spectrum of the whole photo signal shown in Fig. 3(B). (data length: 1second) B. Time series decomposition of the FFT power spectrum of the photon signals. The intervals of the plots are 10ms. Each plot is the peak value of the FFT power spectrum at 5kH for the data length of 10ms.

Figure 3B shows the output signal of the photo detector recorded by the data logger. Whole length of the signal is 1 second. The sampling rate was 1 Mbit/second. The signal of about 20mV was in good agreement with the theoretically calculated value, which is obtained by the LED power density on the ground, collecting area of the optics and the sensitivity of the photo detector. In spite of large noise signal, small periodical LED light signals can be seen every 100ms.

Even at the observation site, which was in a mountain area far away from big cities, the largest noise source was the stray light from the sky, which is considered to be mainly the reflection of the artificial light by the aerosol in the air. The dark current of the photo detector was not the essential noise source and about 1/30 of the stray light noise.

Figure 4A shows the FFT (First Fourier transform) spectrum of the temporal signal shown in Fig. 3B. The central frequency of the spectrum can be seen clearly at 5 kHz, which is in good agreement with the modulation frequency of the macro pulse. The whole spectral width of about 30 Hz can be explained using the pulse width of the macro pulse (30ms), and calculated to be

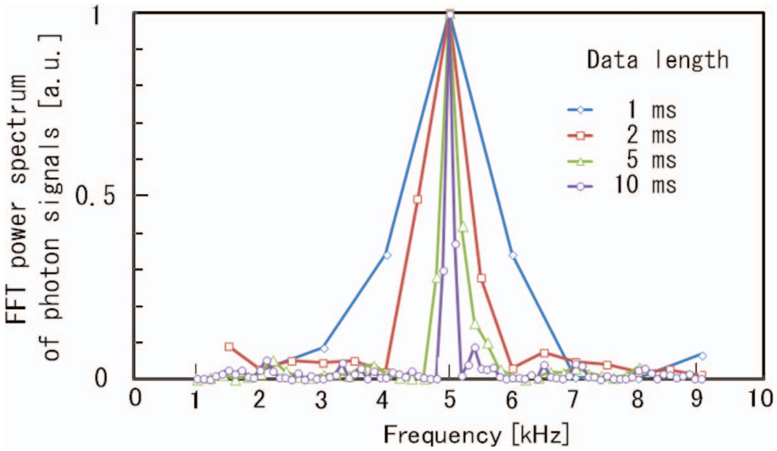


FIG. 5. FFT spectrum of signal of the photo detector. Even for the data length of 1ms, the spectrum peak at 5kHz can be clearly seen.

the inverse of this value. The free spectral range of 10 Hz in the frequency space is explained by the period of the macro pulse (0.1 second), and calculated to be the inverse of this value. The spectral with of fine structure (about 1Hz) is explained using the whole temporal length of the signal (1second), and calculated to be the inverse of this value.

In spite of the poor S/N of the original temporal waveform of the optical signal shown in Fig. 3B, all of the temporal configurations have been clarified clearly by use of Fourier analysis.

In Fig. 4B, time series decomposition of the FFT power spectrum of the photon signals is shown. Each plot is the peak value of FFT power spectrum at 5kHz for the data length of 10ms. Periodical pulse train of 10Hz can be clearly reconstructed. Whole pulse duration of about 1 second is determined by the time in which the FITSAT-1 passes through the sight area of the telescope.

The data length for Fourier analysis was shortened down to 1ms to find the minimum data length by which the spectrum peak of 5kHz appears. Figure 5 shows the results of Fourier analysis for shorter data length (1ms, 2ms, 5ms, and 10ms). The data arias were set in the range of the macro pulse, where the signals exist.

It can be seen that the spectrum width becomes wider inversely proportional to the data length in accordance with the Fourier transformation theorem, as the data length becomes shorter.

Even for the data length of 1ms, the spectrum peak at 5 kHz can be clearly observed. It means that this original optical signal can be read clearly every 1ms interval, and consequently the data transmission rate of as short as 1kbit/second is possible. Moreover, this analysis shows the potentiality of the data transmission rate of more than 1 kbit/second of this experiment.

IV. DISCUSSIONS

The following is the theoretical calculation about the expected signal transmission speed of the system used in this experiment. The LED power density measured at the point on the optical axis of the LED emission and being 540 km away from the satellite is estimated to be

$$\rho \cong \frac{4[\mathrm{W}]}{\pi \times (5.4 \times 10^5[\mathrm{m}])^2} = 4.4 \times 10^{-12}[\mathrm{W/m^2}].$$

The number of photons detected by the photo detector for one second is calculated to be

$$n = \frac{\rho s n}{E} = 6.2 \times 10^4\,[\mathrm{s^{-1}}]$$

where s is the area of the collecting optics (4.9×10^{-2} m^2), E is the photon energy for 520 nm (3.82×10^{-19} J) and $\boldsymbol{\eta}$ is the quantum efficiency (conversion efficiency for the photons to the electrons) of the photo detector (0.11).

Considering that several photons are necessary to recognize the signal of one bit, the optical signal transportation system used in this experiment have the potentiality for the signal transmission speed of about 10kbit/sec. In Fig. 5, the FFT power spectrum can be clearly seen, even the data length is as short as 1ms, which shows that the transmission speed of more than 1 kbit/second is possible, if the dark current of the photo detector and the stray light noise are small enough.

V. CONCLUSIONS

The first observation and the analysis of the LED light emission from the space to the ground are described. A small cube satellite named FITSAT-1 mounting LEDs (Light Emitting Diodes) is released from the ISS (International Space Station). The power density of the LED emission of 4W on the ground was about 4×10^{-12} W/m^2 in average, which is equivalent to the star of the 8.5th grade in average. The frequencies of the macro pulses (10Hz) and the micro pulses (5kHz) of the LED signal, were correctly clarified using the Fourier analysis. As the optical communication experiment, the data transmission rate of more than 1 kbit/second was shown.

ACKNOWLEDGMENTS

Authors thank JAXA (Japan Aerospace Exploration Agency) for the continuing supports to perform "FITSAT-1" project, and also thank Center for Nanosatellite Testing, Kyushyu Institute of Technology, for the thermal vacuum test and the vibration test of FITSAT-1.[10]

[1] H. Heidt, J. Puig-Suari, A. S. Moore, S. Nakasuka, R. J. Twiggs, *14th Annual/USU Conference on Small Satellites* (SSC00-V-5) (2000).
[2] K. Tanaka, T. Tanaka and Y. Kawamura, *Proceedings of UN-Japan Nano-Satellite Symposium*, NSS-04-0209, Nagoya (Japan), Oct.10, 11 (2012)
[3] Y. Mizoguchi, K. Feng, T. Soda, T. Otsuka, T. Kinoshita, K. Nishimoto, Y. Kawamura and T. Tanaka, *UN-Japan Nano-Satellite Symposium*, NSS-04-0111, Nagoya (Japan), Oct.10, 11 (2012)
[4] H. Masuda, K. Okamoto, Y. Wakayama, M. Kamemura, A. Nakajima, N. Sako and E. Hashimoto, Technical Report of the Institute of Electronics, Information and Communication Engineers, vol.110, 31–36 (2011).
[5] Private communication with Mr. S. Hong (ISSO: Open source satellite initiative).
[6] Y. Fujiwara, M. Mokuno, T. Juono, T. Yamawaki, K. Arai, M. Toyoshim, H. Kunimori, Z. Sodnik, A. Bird, and B. Demelenne, Acta Astronautica **61**, 163–175 (2007).
[7] Y. Kawamura, M. Kawai, and K. Toyoda, Japan Journal of Applied Physics **7**, 2013 (1988).
[8] H. Ishizuka, Y. Kawamura, K. Yokoo, H. Shimawaki, and A. Hosono, Nuclear Instrument and Methods in Physics Research **A 475**, 593 (2001).
[9] K. Takeuchi, Y. Fukusumi, H. Yokoyama, H. Noguchi, and K. Igarashi, Journal of Illuminating Engineering Institute of Japan **94**, 116 (2008).
[10] M. Cho, H. Masui, Y. Akahoshi, K. Hiraki, M. Iwata, K. Toyoda, and S. Hatta, *Proceedings of the 2nd Nano-Satellite Symposium* (2011).