Preliminary study on diffuse OWC for intra-CubeSat Communication

Ezgi Ertunc
Scuola Superiore Sant'Anna
Pisa, Italy
ezgi.ertunc@santannapisa.it

Alessandro Messa
Scuola Superiore Sant'Anna
Pisa, Italy
a.messa@santannapisa.it

Lorenzo Gilli
Scuola Superiore Sant'Anna
Pisa, Italy
lorenzo.gilli@santannapisa.it

Giulio Cossu
Scuola Superiore Sant'Anna
Pisa, Italy
g.cossu@santannapisa.it

Mario Rannello
Scuola Superiore Sant'Anna
Pisa, Italy
mario.rannello@santannapisa.it

Ernesto Ciaramella
Scuola Superiore Sant'Anna
Pisa, Italy
e.ciaramella@santannapisa.it

***Abstract*—Here we present the experimental characterization of 1 Mbit/s optical wireless communication system by simulating an intra-CubeSat environment where we exploit the reflections to transmit in the 2U CubeSat. The optical system uses infrared-LEDs, silicon-Avalanche photodiode, digital optical power meter and optical attenuators.**

Keywords—optical wireless communication, CubeSats, free space optics, intra-satellite communication, non-line-of-sight link

I. Introduction

Recently, applications of CubeSats are significantly increasing in the space technology. They belong to the nanosatellite family where the smallest design size is the 0.25 unit (2.5 cm^3) and the largest is 12U (120 cm^3) [1]. The outer dimension of 1U satellite is 10x10x10 centimeter with a mass of less than 1.33 kilograms. There is possibility to integrate the satellite bodies as 2U, 3U, 6U. Nowadays, CubeSats are playing a very important role in the satellite economy. CubeSat market is expected to grow by 19% from 2018 to 2023 [2]. Their market range is around a few million thousand dollars [3]. Since 1998 until 2019, nearly 2100 CubeSats were launched to the orbit [4]. Therefore, within the next few years, the CubeSats launches are expected to double respect to the last years. There are various promising applications in CubeSat industry on scientific, technology and Earth observation such as high-resolution solar imaging, mission beyond low Earth orbit, Direct/Indirect to Earth communication [5].

CubeSats communication mostly operates with radio frequency (RF) to provide the ground communication at ultra-high frequency (UHF), S-band or X band. Their frequency allocation is based on International Telecommunication Union (ITU) [6-8]. Due to relevant electromagnetic interference, it is inconvenient to use radio frequency inside the CubeSat.

As they are emerging technology, the next decade is likely to see various solutions on different approaches for space applications such as development time, cost, reliability, mission lifetime and replacement, as seeing in [9-11].

Since they are very tiny satellites placed in low earth orbit (LEO), the harness and cabling for communication of the systems and boards represent a significant percentage of their mass; for this reason, it is essential to find an alternative wireless solution.

Recently, optical wireless communication (OWC) was proposed to overcome these issues by removing the cables, and to replace them by optical transceivers. Since its frequency range is from infrared (IR) to visible light, there is no electromagnetic interference problem. Optical wireless links for satellite communications for intra-Spacecraft have some issue and a strong potential for the future applications [12]. We are introducing a new approach of OWC system for satellite [13], which is based on the most recent achievements of indoor OWC and aims at realizing practical transceivers. To achieve this goal, we plan to use only the most suitable commercial off-the-shelf (COTS) components among those at low cost and low power consumption .

In this paper, we report a preliminary experimental study of a non-line-of-sight (n-LoS) IR OWC link for intra-CubeSat communication. This work can help to understand the OWC system robustness and realize the best optical transmitter. We show characterization of the system by means of the eye diagrams and bit error ratio (BER) of the received signal.

II. Experimental Setup and Experiment

In our experiment, we realized two blackboard boxes (2 x 10x10 cm) to simulate a 2U CubeSat environment. Obviously, there is a hole that provides connection between the two units. The scheme of our OWC system setup is shown in Fig.1. We performed optical communication transmission by using either 850 nm or 940 nm IR LEDs as transmitter (TX); in both cases the receiver (RX) was a 10×10 mm active area Avalanche Photodiode (Si-APD, 11MHz bandwidth).

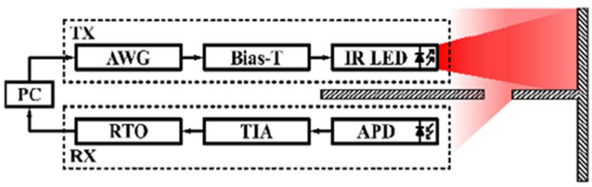
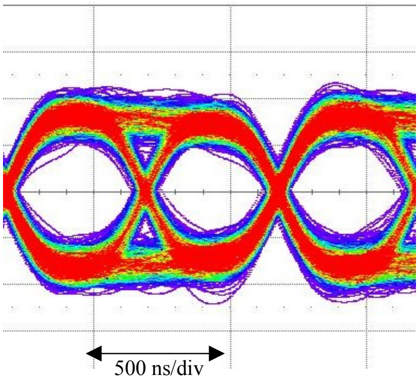
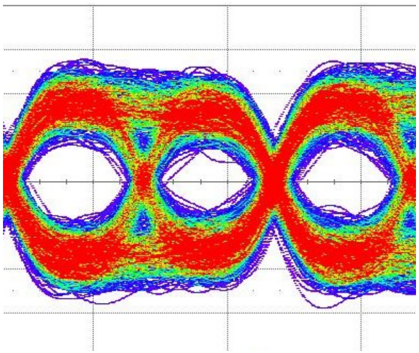


Fig. 1 OWC system setup



(a) 850 nm IR-LED



(b) 940 nm IR-LED

Fig. 2 Eye diagrams of the system of n-LoS link in the intra-CubeSat, taken at the same received power, i.e. -30 dBm, using 850nm IR-LED (a), or 940 nm TX (b). The time scale is 500 ns/div

Using MATLAB, we generated a 1 Mbit/s Manchester coded pseudorandom binary sequence (PRBS). We chose Manchester coding as it is well known that it has no DC component, therefore it is an ideal coding for our AC coupled Si-APD receiver.

The transmitted signal is then generated by means of an Arbitrary Waveform Generator (AWG). Then, 300 mV amplitude of electrical signal is amplified and superimposed to a 0.4 A continuous current utilizing a bias-T, in order to drive the IR LED. Then, the produced signal light is reflected from the wall to the RX and collected by the Si-APD RX; a PM400 digital power meter is used to calculate the received optical power. At the APD receiver the transimpedance amplifier (TIA) converts the generated photocurrent to a voltage signal. Then, the signal is acquired by a real time oscilloscope (RTO) at sampling rate of 200 MS/s. Before BER analyses in MATLAB, a 1.6 MHz digital low-pass filter is applied .

According to a real intra-CubeSat, its environment is dark and full of electronic equipment, boards and cables. Therefore, the design of OWC link in intra-CubeSat benefits from n-LoS configuration. Direct line-of-sight (d-LoS) configuration is to observe the link sensitivity. To evaluate the system performance, we repeated the BER measurement at different received optical power values, using different optical attenuators on the RX side.

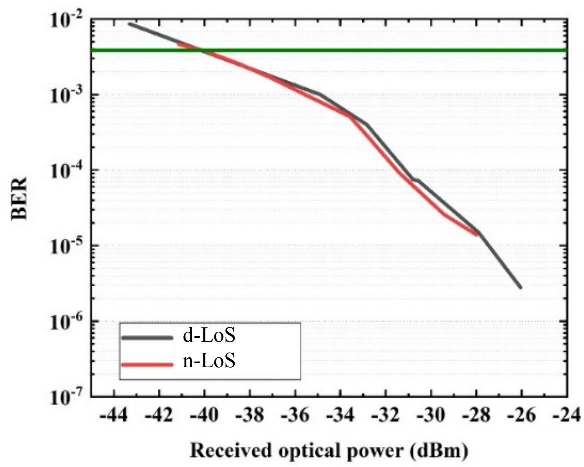
We repeated the BER measurements using two different wavelength IR-LEDs. The first experiment was to measure the link sensitivity by d-LoS measurements using TX 850 nm and 940 nm. We also performed an experiment to understand the performance of the n-LoS reflection from the walls of the CubeSat.

III. Results

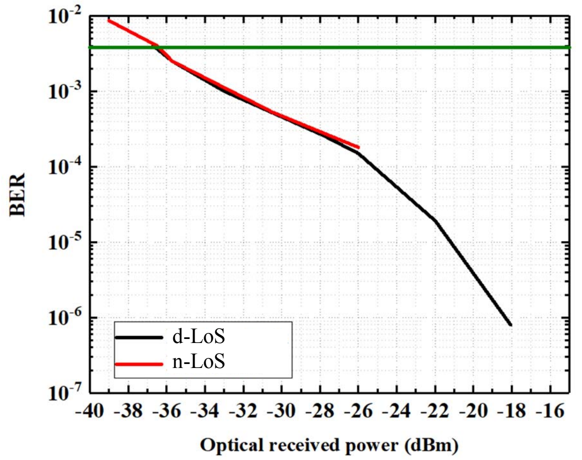
To check the quality of the received signals, Fig. 2 reports the eye diagrams after reflection for both 850 nm and 940 nm. The signal has lower distortion when using TX 850 nm IR-LED. It has the largest eye opening and easily observing the decoded signal.

Fig 3. reports the BER values as a function of optical received power. The black and red curves indicate the d-LoS link measurement and the n-LoS reflection measurement, and the green line shows the Forward Error Correction (FEC) limit of 3.8×10^{-3} [14].

We measured the BER performance for LoS link by using 850 nm and 940 nm and found the sensitivity of -40 dBm and -36.5 dBm (at the FEC limit), respectively. There is ~5 dB difference between 850 nm and 940 nm IR LEDs performance, mostly due to the spectral response of the Si-APD receiver. When utilizing the n-LoS reflection from walls, we obtained BER of 2.6×10^{-5} and 5.3×10^{-4} at power of -30 dBm by using 850 nm (a) and 940 nm (b) IR LED at the TX side, respectively. In this condition, we did not obtain any error after the transmission of 4×10^{5} bits.



(a) 850 nm IR-LED



(b) 940 nm IR-LED

Fig. 3 Measured BER vs. optical received power when using as transmitter a 850 nm IR-LED (a) and a 940 nm IR-LED (b).

As shown in Fig.3, d-LoS and n-LoS measurements are overlapping; this is a proof that the multipath effect is negligible in the system, as could have been expected since we are using non-coherent sources and the bit time of OWC system is 1 µs in the experiment. However, the delay time of different paths is very short, i.e. around few ns.

IV. Conclusion

In this work, we demonstrated a n-LoS IR OWC system for intra-CubeSat communication by utilization the diffuse reflections from the wall of a 2U CubeSat. The OWC system was based on the IR LEDs, Si-APD and digital optical power meter.

First, d-LoS Link configuration was performed to realize the characterization of the IR-LEDs. Then, n-LoS link was performed to assess the sensitivity of the optical system. We found that the link sensitivity at FEC limit is at -40 dBm and -36.5 dBm by using 850 nm and 940 nm IR LED, respectively. We found the best eye opening when using 850 nm IR LED and Si-based APD and we observed a BER value of 2.6×10^{-5} at -30 dBm power.

This preliminary study allows better understanding of intra-satellite OWC system and it will be helpful for the future activities.

Acknowledgment

This work was partly supported by Italian Space Agency (ASI) under project Free Space Optical Communications for Space Applications (FOCS).

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