UDC 621.391.8

OPTICAL INTER-SATELLITE LINK IN COMPARISON WITH RF CASE IN CUBESAT SYSTEM

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The paper is received on September 22, 2017

Abstract. The CubeSat is the format of small satellites that is frequently used for scientific purposes. However, communication is also in the focus of CubeSat research projects. Cooperative schemes for these satellites are required for more robustness and capacity. Hence, inter-satellite links (ISL) are necessary. This research project deals with implementation possibilities of optical ISL in the CubeSat format. The most common type of communication used in wireless systems is the radio frequency (RF) communication. However, nowadays space optical communication promises more benefits, first of all, higher data rate, security, lower power consumption and reduction of satellite mass. However, along with the advantages it also has disadvantages: the problem of pointing accuracy and maintenance of the link during movement. During this research the most famous satellite projects with optical communication links are considered for review of the main advantages and disadvantages of this type of communication in space. The typical link budgets for CubeSat are calculated for two cases: optical and RF for estimation of opportunities of ISL. Problems that links to accuracy and pointing are described as the factor of limitation of optical case. Results can be used for estimation of possibilities of current CubeSat equipment and for evaluation of opportunities of space optical communications. Moreover, described problems are the main topics for future research in this field of science.

Key words: Cubesat, intersatellite link, optical communication.

1. Introduction

Nowadays the tendency to minimizing sizes of devices and systems is increasing. Additionally, questions about optical communications, that are well discussed for terrestrial systems (also by our colleagues in TU Ilmenau, Germany, from whom authors of this paper obtained suggestions and corrections) [1–4], are also in the focus of research in application to small systems. These tendencies have touched also satellite field. Thus in 1999 professors Jordi Puig-Suari of California Polytechnic State University and Bob Twiggs of Stanford University presented the first design of the miniaturized satellite CubeSat [5]. The type of the satellite was intended only for research projects, which could be used by students. However, the idea of small satellites becomes more popular among radio engineers. Today many companies are interested in tiny and cheap satellites, which can provide similar services (space research, Earth observation, amateur radio).

2. CubeSat Satellites Background

CubeSat is a format of the Low Earth Orbit (LEO) satellite with mass about 1.13 kg per unit. Beside the 1U (1 unit) format with 3-dimentions parameters 10x10x10 cm there are other formats (Table 1).

Table 1: Requirement to CubeSat format [6]

CubeSat format	Dimensions, cm	Mass, kg
1.5 U	15x10x10	2
2 U	20x10x10	2.66
3 U	30x10x10	4
6 U	30x20x10	12

The most popular and extensive projects with CubeSats are listed below [7].

- International QB50 program, under the leadership of von Karman Institute and the company ISIS (the Netherlands, China and Russia). It plans to deploy an group of 50 CubeSat satellites for scientific research of the lower layers of the thermosphere;

- Colony I (USA) program that provides 12 CubeSat launch in the next few years;
- Colony II program as part of plan to launch an additional 20 to 50 after the Colony I CubeSat program completion;
- Program Edison Demonstration of Smallsat Networks, which NASA plans to launch at The Athena 2 in 2013, eight 1.5U CubeSat to start testing the inter-satellite communication system with the broadest application of the different areas;

There are several types of CubeSat communication in space: CubeSat - ground, CubeSat - large satellite, CubeSat - CubeSat.

As for the CubeSat to ground communication example, the NASA has developed an optical CubeSat communication system (Fig. 1). Aerospace proposed optical communications using a milliradian (mrad) beam width, which is compatible with near-term CubeSat pointing capabilities. The baseline mission will use a 10 W modulated fiber laser with a 1.4° angular beam-width on a 1.5U CubeSat (AeroCube-OCSD) and a 30 cm diameter telescope located on Mt. Wilson in southern California to receive the optical signal. The project plans on demonstrating a 5 Mbit/s optical link with a stretch goal of 50 Mbit/s [9]. In this paper we will consider the third type of link: CubeSat to CubeSat.

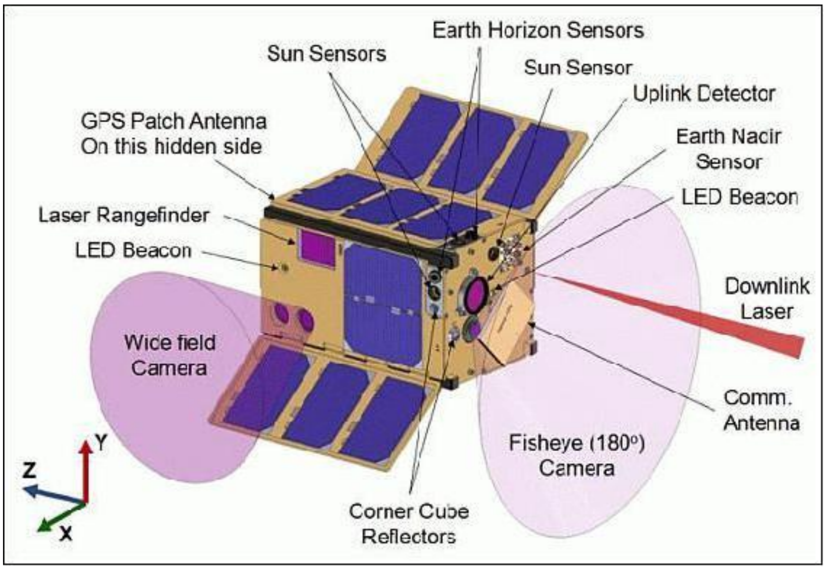

Fig.1: Schematic rendering of AeroCube-OCSD nanosatellite (image credit: The Aerospace Corporation) [9].

3. Inter-satellite link

An inter-satellite link (ISL) is a link between satellites (Fig. 2) and this type of the link is necessary because ISL provides communication and exchanging information directly between satellites and can be a data relay to ground. The most common type is radio frequency (RF) communication. Nevertheless, the interest in another link type, namely, optical links, is increasing. Optical communication can provide many benefits compared to RF.

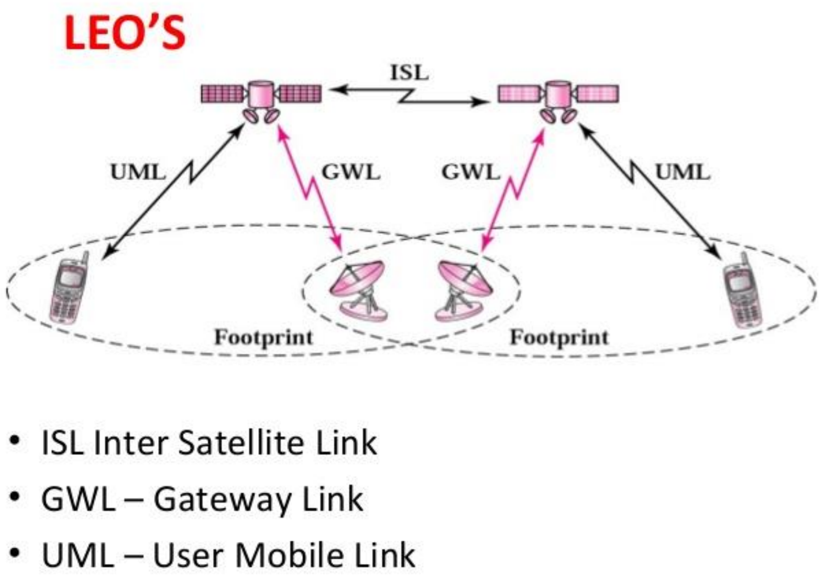

Fig. 2: Inter-Satellite Link model [16].

An example for a project that uses RF ISL between CubeSats is the QB50 project. The QB50 mission will demonstrate the possibility of launching a network of 50 CubeSats that are built by universities teams all over the world as a primary payload on a low-cost launch vehicle to perform first-class science in the largely unexplored lower thermosphere [8]. Distance between CubeSats is 90 km. The uplink and downlink data rates are 9600 bps and inter-satellite link data rates will take different values in the simulations: 0.5 kbps, 1 kbps, 3 kbps, 6 kbps, 8 kbps and 10 kbps.

An optical ISL is not implemented into CubeSat system yet. It should be taken into account that there are examples of successful optical ISLs in large (~1000 kg) and small satellites (~100 kg) (section 4).

In this paper we consider both cases of ISL (RF, optical) and discuss their suitability in CubeSat format. The optical inter-satellite link (OISL) budget is described in section 4. The RF link budget is described in section 7. Comparison RF and OISL is presented in section 8.

4. Optical ISL

An optical inter-satellite link can offer important advantages compared to RF: higher data rate; higher directivity of beam and thus; lower path loss.

However, a narrow beam is not only a benefit, but also a problem. In the CubeSat format we have a lot of limits on dimensions, power consumption. The questions of pointing, acquisition and tracking in that system need also to be addressed. The possibilities of implementation that system is considered in 2.2 section.

The most known projects with optical ISL are:

1. Semiconductor Inter satellite Link Experiment (SILEX) (large satellites) (LEO-GEO: 36500 km, 42000 km) [10];

2. STRV-2 is an experimental package built by JPL for flight on the Space Test Program small satellite TSX-5 (not larger than 100 kg). AstroTerra company, mass of the terminal is 14 kg, power consumption about 56 W in standby and 95 W in operations, data rate is up to 1.24 Gbps, launched for 1600 km (sat-to-sat) and 1700 km (sat-to-gnd) distances [11];

3. LaserCom (Laser Communication Experiment): to demonstrate high data rate infrared laser communications between a satellite and other platforms. Mass is 14.3 kg, transceiver telescopes are 13.8 cm diameter, power consumption is 125mW each, wavelength is 810 nm (80 mrad divergence), two acquisition/tracking lasers with consumption about 100 mW each (852 nm, 500/1500 mrad divergence) [11].

5. OISL budget

For the comparison of the two types of communication we assume some initial parameters for link budget calculation (Table 2).

Table 2. Initial parameters for optical case.

Parameters	Value	Measurement unit
Transmitted power, P_{tx}	1	W
Distance between satellites, R	$100{\cdot}10^3$	m
Wavelength, λ	$1550{\cdot}10^{-9}$	m
Bit rate, R_b	10^6	bps

Assuming transmit power and wavelength are the most common, distance has been chosen according to [9].

The simplest and most common modulation scheme for optical communication is On-Off Keying (OOK). For a rectangular pulse shape, intensity modulation and direct detection, the transmitted optical signal is given as:

$$p_{tx}(t) = \sum 2P_{tx}b_n \cdot rect\left(\frac{t - nT_b}{T_b}\right) \tag{1}$$

Where $p_{tx}(t)$ is the instantaneous optical power, P_{tx} is the average optical power, $R_b = \frac{1}{T_b}$ is the data rate, $b_n \in 0{,}1$ denotes the bits to be transmitted.

The theoretic limit of the required power P_{tx} on the receiver results from the quantum nature of the light, since at least one photon needs to be detected for transmitted 1-bit. On average $N_{ph} = 10$ photons need to be detected per bit, if the Poisson distribution of the received signal is considered and the required BER is 10^{-9}. The minimum required energy per bit is therefore [13] ($h = 6.62 * 10^{-3}\ m^2\text{kg/s}$ is Plank constant, *f=c/* λ is optical frequency.):

$$E_{b,req} = N_{ph}hf, N_{ph} = 10 \tag{2}$$

If we use a PIN photodiode, where we have a lot of additional noise in the preamplifier, an estimation of the required received photons N_{ph} is now 10000, and for an APD (avalanche) photodiode an estimation is 1000, according to [13].

The minimum required receive power is therefore:

$$P_{req} = \frac{E_{b,req}}{T_b} = N_{ph}hfR_b \tag{3}$$

We use the common link budget equation, which considers gains and losses of the system, on the linear scale, to calculate the actual Rx-power:

$$P_{rx} = G_{tx}L_{rx}P_{tx} \tag{4}$$

where G_{tx} is gain of the transmitter, L_{rx} is path loss including the Rx-gain (all terms are on a linear scale).

Optical laser communication is based on a precisely directed laser beam. Thus, one of the most important parameter in optical communication is the divergence angle θ_{div}.

Gain of the transmitter depends on θ_{div} and is defined that way for a Lambertian radiator [14]:

$$G_{tx} = \frac{I_0}{I_{0,iso}},\ where\ I_{0,iso} = \frac{P_{tx}}{4\pi} \tag{5}$$

$$I_0 = \frac{P_{tx}}{2\pi}(m+1), \text{где}\ m = \frac{ln2}{ln(cos\theta_{div})} \tag{6}$$

I_0 is the radiant intensity in W/srad, m is lambertian order [15], related to divergence angle.

Since the path loss is given as

$$L_{rx} = \frac{A_{rx}}{4\pi R^2} \tag{7}$$

$$P_{rx} = \frac{P_{tx}}{4\pi} \cdot \frac{1}{I_{0,iso}} \cdot \frac{A_{rx}}{R^2} \tag{8}$$

Where $A_{rx} = \frac{\pi}{4d_{rx}^2}$ is receive area and receiver gain, which depends on diameter of the receiver, d_{rx} is diameter of the receiver.

$$P_{rx} = \frac{A_{rx}}{2\pi R^2}\left(1 - \frac{ln2}{ln(cos\theta_{div})}\right)P_{tx} \tag{9}$$

The dependence on the parameters is shown on the Fig.3.

Fig. 3 shows that the larger aperture size and divergence angle, the lower power, which possible to receive. Thereby, we see, that for certain R_b is the most appropriate parameters of angle and aperture are laying below realistic receive power limit.

In the following we describe a more precise sensitivity calculation for PIN and APD photodetectors.

Two types of photodiode are considered: p-intrinsic-n (PIN) diode and avalanche photodiode (APD). Actually, they have got advantages and disadvantages. First of all, it should be emphasized that PIN is preferable in wireless infrared communication on the earth communication. Reasons are lower cost, easier to bias. However, APD gives the more strong gain, providing a much greater level of sensitivity.

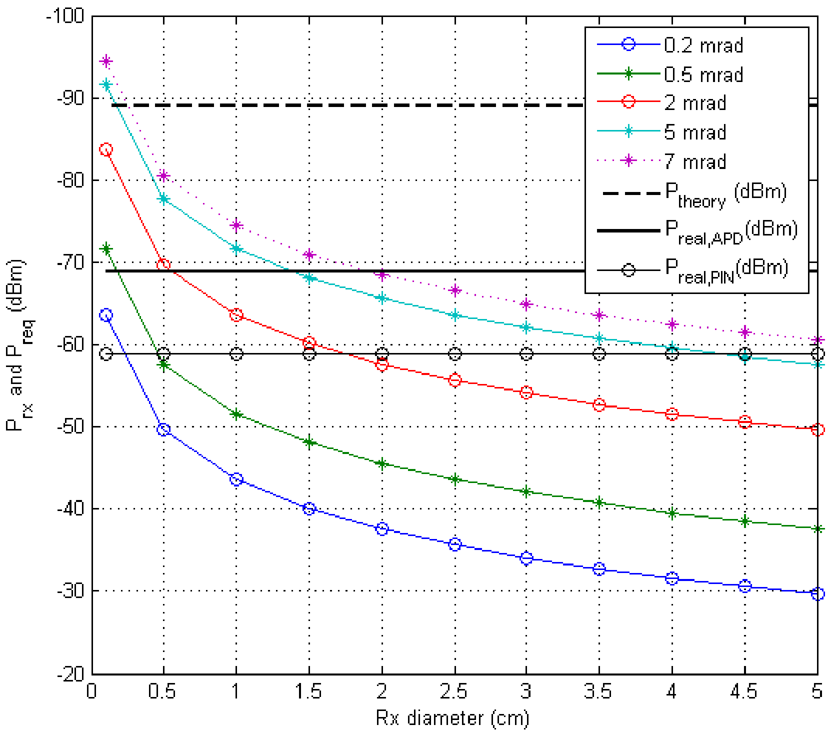

Fig.3. P_{rx} and P_{req} (dBm, theoretical and realistic limits for PIN and APD) in dependence on Rx diameter d_{rx} (cm) and divergence angle θ_{div} (mrad) with P_{tx}=30 dBm.

Let us assume some initial parameters from the [14, 17] in Table 3.

Table 3: Initial parameters for noise calculation in PIN case

Parameters	Value	Measurement unit
Capacitance of the photodiode, C_d	$2{\cdot}10^{-12}$	F
Absolute temperature, T	290	K
Value of Personick integral for thermal noise, I_2	0.562	
Electron charge, q	$1.6{\cdot}10^{-19}$	C
Base-emitter current, I_{BE}	$1.25{\cdot}10^{-6}$	A

In order to derive the (more realistic) value of $R_f \approx 8$ MOhm for a PIN/APD, we first calculate the noise variances according to [14]. Assume bipolar transistor, so we get:

$$\sigma_{PIN}^2 = \left(\frac{4kT}{R_f} + 2qI_{BE}\right) I_2 R_b \tag{10}$$

$$R_f = \frac{100}{2C_d \pi P_b} \tag{11}$$

Where R_f MOhm is preamplifier load resistance, defined in equation 11.

In the APD case, there are other terms for the noise variance. It should be noted, that thermal noise term is the same. However, due to the feature of APD, it has its own noise, which will be also increased in amplification the photodiode. For this case we use parameters from [14, 17, 18] (Table 4).

Table 4. Initial parameters for noise calculation in silicon APD case

Parameter	Value	Measurement unit
Electron charge, q	$1.6 \cdot 10^{-19}$	C
Dark current, I_d	$0.05 \cdot 10^{-9}$	A
Typical gain (linear scale), M	100	
Excess Noise Factor (at typical gain, linear scale), F	7.9	
Value of Personick integral for thermal noise, I_2	0.562	

Using parameters from Table 4 we can calculate the noise variance for APD case as [14]:

$$\sigma_{APD}^2 = \frac{4kT}{R_f} I_2 R_b + 2qI_d M^2 F I_2 R_b \tag{12}$$

The Bit Error Rate (BER) depends on the type of the modulation, received power, noise and responsivity of the detector system.

Assuming Gaussian noise, the equation 13 represent the resulting BER in PIN case:

$$P_b = \frac{1}{2} erfc\left(\frac{RP_{req}}{\sqrt{2\sigma_{noise}^2}}\right) \tag{13}$$

Where R is detector responsivity [19], $P_{req}$is the received power, σ_{noise}^2 is the noise variance, $erfc(x)$ is the complementary error function [20]. It is defined in 14.

$$erfc(x) = \frac{1}{\pi}\int_x^{\infty} e^{-t^2} dt \tag{14}$$

However, in APD case we should take into account the gain *M* from Table 4:

$$P_b = \frac{1}{2} erfc\left(\frac{RP_{rx,req}M}{\sqrt{2\sigma_{noise}^2}}\right) \tag{15}$$

Therefore, if we fix $P_b = 10^{-9}$, we can compute required received power as:

For PIN case:

$$P_{req,PIN} = \frac{erfcinv(2P_b)\sqrt{2\sigma_{noise}^2}}{R} \tag{16}$$

For APD case:

$$P_{req,APD} = \frac{erfcinv(2P_b)\sqrt{2\sigma_{noise}^2}}{RM} \tag{17}$$

Finally, with assumptions from Tables 2, 3, 4, we achieve required Rx sensitivity for different photodetectors in Table 5.

Table 5. Rx sensitivity for photodetectors for 1 Mbit/s

Type of PD	Required Rx sensitivity, dBm
PIN	-52.9
APD	-65.5

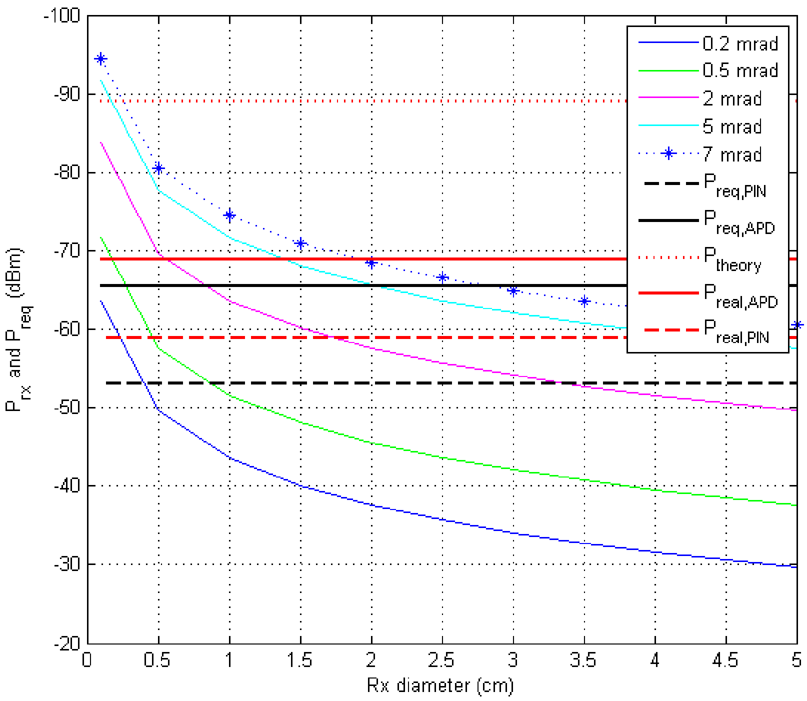

Fig. 4: P_{rx} and P_{req} (dBm, theoretical and realistic limits for PIN and APD) in dependence on Rx diameter d_{rx} (cm) and divergence angle θ_{div} (mrad) with P_{tx}=30 dBm.

Figure 4 shows us that link may be possible with our assumptions if we use APD photodetector as a receiver and laser with $\theta_{div} = 0.2$ mrad, $\theta_{div} = 0.5$ mrad or $\theta_{div} = 2$ mrad as a transmitter.

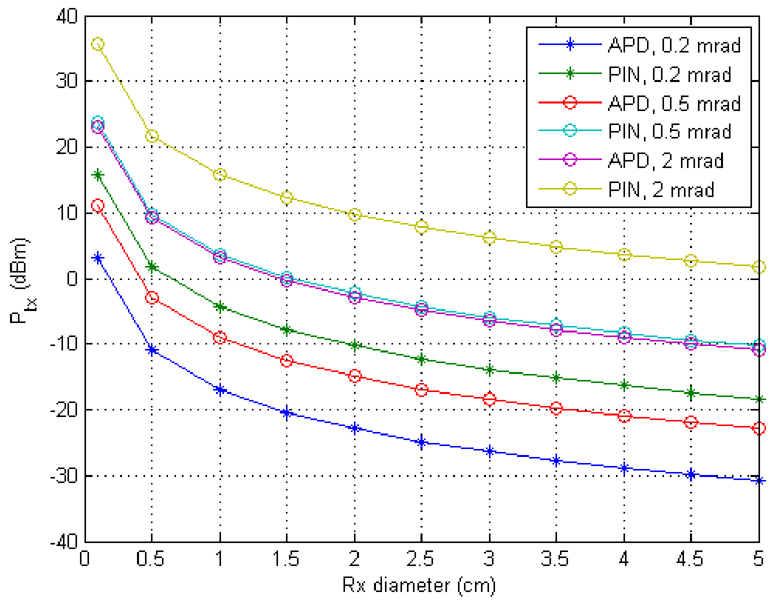

Fig. 5: Required Tx power (dBm) over Rx diameter d_{rx} (cm) and divergence angle θ_{div}. Margin 5 dB.

Figure 5 shows us dependence transmit power on the aperture size and divergence angle.

Besides link budget calculation the question pointing, acquisition and tracking (PAT) is stayed very important.

6. Pointing, acquisition and tracking system

The pointing, acquisition and tracking (PAT) system is the most critical item in optical IS communication due to the narrow transmit beam. In the large satellites this problem can be solved by the big aperture size, e.g. 30 cm diameter, wider divergence angle and higher transmit power. However, in CubeSat it is impossible, first of all, because of the dimensions of format, the overweight and power possibilities.

Idea of PAT system consists in acquiring and tracking the counter terminal incoming laser beam as well as in pointing the transmitter terminal`s outgoing beam with an accuracy which enables data transmission between two satellites. There are three modes [22]:

1. **Acquisition control**: for compensation initial beam pointing error due to spatial acquisition errors from spacecraft location prediction errors. The strategy of this phase is beam scanning (by beacon laser) the region of space where the receiver is expected to be located, this is need a wide beam to reduce the acquisition time, which requires a high power optical transmitter, typical time for this phase is about 10 s [23].
2. **Tracking control**: after beam acquisition, it track out local angular disturbances transmitted from the host platform and the dynamic elements of the payload with submicroradian accuracy.
3. **Pointing control**: wherein the terminal`s optical head is pointed towards the opposite satellite after compensation for reactive platform motions and finite transmit time of light.

As it was said above (section 1.1), NASA had investigated and implemented optical downlink in CubeSat (OCSD: Optical Communication and Sensor Demonstration Program). OCSD is a two-CubeSat flight test developed by the

Aerospace Corporation, selected by NASA’s Small Spacecraft Technology Program (SSTP) to be launched in late 2015. The OCSD baseline mission is to establish an optical communication link of 5-50 Mbps from the satellite in LEO to a 30-cm diameter telescope at Mt. Wilson in Southern California [9, 25].

Also they designed PAT system for the connection establish. The OCSD CubeSats utilize a combination of *coarse* and *fine sensors* to accomplish a pointing accuracy of 0.1^o, sufficient to meet the pointing requirement imposed by the downlink beam width. The coarse sensors include six 2-axis sun sensors, four Earth horizon sensors, a two-axis nadir sensor, and two sets of 3-axis magnetometers. The coarse sensor suite is capable of achieving continuous attitude knowledge to 0.1^o accuracy. Fine attitude determination is accomplished by close-loop tracking of a 10-W uplink beacon at 1550 nm. The up-link beacon detector is a 3-mm diameter InGaAs quad photodiode, accompanied by a 18-mm lens system and narrow-band filter. The fine attitude determination system with laser beacon detection can achieve an accuracy 0.1^o in attitude knowledge [9, 25].

Authors of [25] suggest their system for improving NASA results. The NODE (Nanosatellite Optical Downlink Experiment) system is a CubeSat-size communication module, designed to establish a 10-50 Mbps laser communication downlink from LEO. NODE uses a 2-W laser at 1550 nm with 2.1 mrad (0.12^o) beam divergence to support the communication link. An uplink beacon at 850 nm is transmitted from the ground station to provide precise ground station acquisition and tracking. In addition to the primary laser downlink, the NODE architecture also includes a low-rate bi-directional RF link for telemetry, command, and back-up transmission when the laser link is not available. The NODE architecture is summarized in Figure 5.

Furthermore, the big problem facing the OISL between two satellites is the satellite vibration and the relative velocity between the two satellites, which is not zero [23]. However, the precise stabilization system can reduce the scanning area for searching receiver and therefore the link can be done. The stabilization system for CubeSats has 2-degree pointing accuracy with no star-tracker (is an optical device that measures the position of star using photocell or a camera) and 0.1 pointing performance with it [26].

From this we can conclude that the link establishment is possible.

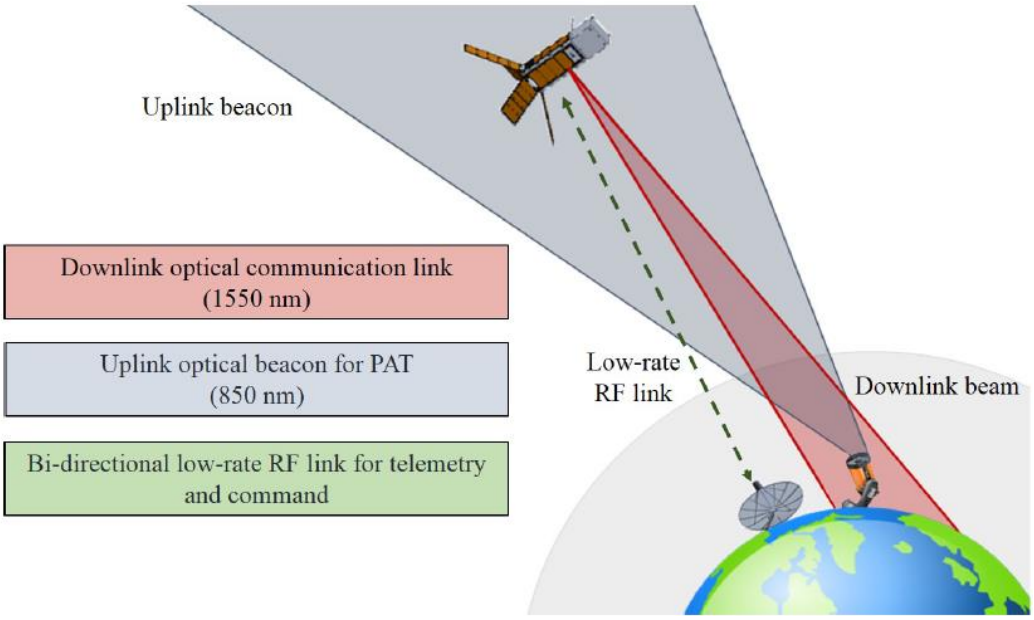

Fig.5: NODE system architecture, consisting of a 1550-nm downlink beam as primary downlink method, a 850-nm uplink beacon for acquisition and tracking, and a bi-directional radio-frequency link for telemetry and command [25].

7. Radio frequency ISL budget

A RF ISL is the most common type of communication in satellite field. It is used for satellite to ground link and vice versa, especially for ISL. Furthermore, long term experience with radio transmission for space-to-ground links makes RF-based inter-satellite communication more reliable and easier to implement in space. On balance, once there is a need for a very high data rate or a very accurate positioning requirement, optical sensors can be the solution. Otherwise, an RF sensor may be preferable for a small satellite mission [27].

For comparison with OISL we have calculated link budget for the RF link too. Assume for simplification that there is not any coding, we use the simplest modulation (BPSK) and there is existing only thermal noise. Obviously, it should be noted, that if we chose some coding scheme, we achieve an additional coding gain.

Table 6: Initial parameters for RF case

Parameter	Value	Measurement unit
Transmitter power, P_{tx}	1	W
Distance between satellites, R	$100 \cdot 10^3$	m
Bit rate, R_b	10^6	bps
Frequency, f_a f_b f_c	$5.8 \cdot 10^9$ [21] $25 \cdot 10^9$ $60 \cdot 10^9$	Hz Hz Hz
Diameter of aperture, d	0.09 [21]	m

The equation for the path loss looks similar as in optical case (4). However, as it was said above, due to different physical phenomena that underlie in optical and radio frequency communication, the way of computing terms from 4 will be differ.

Here we have isotropic radiation from the transmitter, therefore the gain for the transmit antenna can be calculated that way:

$$G_{tx} = \frac{4\pi A_{tx}}{\lambda^2} \tag{18}$$

$$A_{tx} = \frac{\pi}{4} d^2 \tag{19}$$

$$\lambda = \frac{c}{f} \tag{20}$$

where A_{tx} is the transmit area, d is the aperture of the transmitter, λ is wavelength, c is the speed of light. Assume the receiver gain is equal to the transmitter gain with the same parameters.

The path loss for isotropic antennas is:

$$L_{rx} = \frac{\lambda^2}{(4\pi \mathrm{R})^2} \tag{21}$$

Below there is Table 7 with our calculation results.

Table 7. Results of RF link budget calculation.

Case a)	
Transmitter gain, dB, G_{tx}	14.76
Receiver gain, dB, G_{rx}	14.76
Path loss, dB, L_{rx}	147.7
Received power, dBm, P_{rx}	**-88.19**
Case b)	
Transmitter gain, dB, G_{tx}	27.45
Receiver gain, dB, G_{rx}	27.45
Path loss, dB, L_{rx}	160.4
Received power, dBm, , P_{rx}	-75.5
Case c)	
Transmitter gain, dB, G_{tx}	35
Receiver gain, dB, G_{rx}	35
Path loss, dB, L_{rx}	168
Received power, dBm, P_{rx}	**-67.9**

Every circuit has its own noise (it is called as thermal noise) from some elements, e.g. resistor. This noise not so strong and receiver can define the signal through it. Assume there is an ideal ohmic resistor, hence thermal noise density can be defined that way:

$$N_0 = kT \tag{22}$$

where $k = 1.38 \cdot 10^{-23} \frac{m^2 kg}{s^2 K}$ is the Boltzmann constant, T = 270 K is absolute temperature. In dB $N_0 = -174$ dB.

Assuming an AWGN-channel, the required SNR depends on the modulation scheme (BPSK) and the $P_b = 10^{-9}$.

$$\eta_{req} = \frac{E_b}{N_0} \tag{23}$$

$$P_b = \frac{1}{2} erfc\left(\sqrt{\eta_{req}}\right) \tag{24}$$

From 24 we get:

$$\eta_{req} = (erfcinv(2P_b))^2 \tag{25}$$

$$\eta_{req,dB} = 10lg(\eta_{req}) \tag{26}$$

Required power in dBm assuming thermal noise:

$$P_{req,dBm} = N_{0,\mathrm{dB}} + \eta_{req,dB} + 10lg(R_b) \tag{27}$$

With fixed bit rate from Table 7 we achieve $P_{req,dBm} = -102\ dBm$

It means that all value of received power from Table 7 are fulfilled requirement above. To sum up, the link between two CubeSat satellites is possible.

8. Comparison of RF and Optical ISL

Obviously, we cannot adjust receiver sensitivity as we want. However, we can change transmit power, of course, with respect to the system performance. It should be noted, that the power consumption is one of the most important limits in CubeSat. Besides, nowadays a lot of developments are directed to the improvement the solar panels capacity. One of the most common volume of panels for the 3U format of CubeSat is up to 60 W [26].

Nevertheless, there is dependence required transmit power on the distance between satellites: transmit power must be increased with increasing the inter-satellite distance. Figure 7 shows us the difference between power consumption in RF and optical link. And we can see that optical case, actually, has average values compared to the RF.

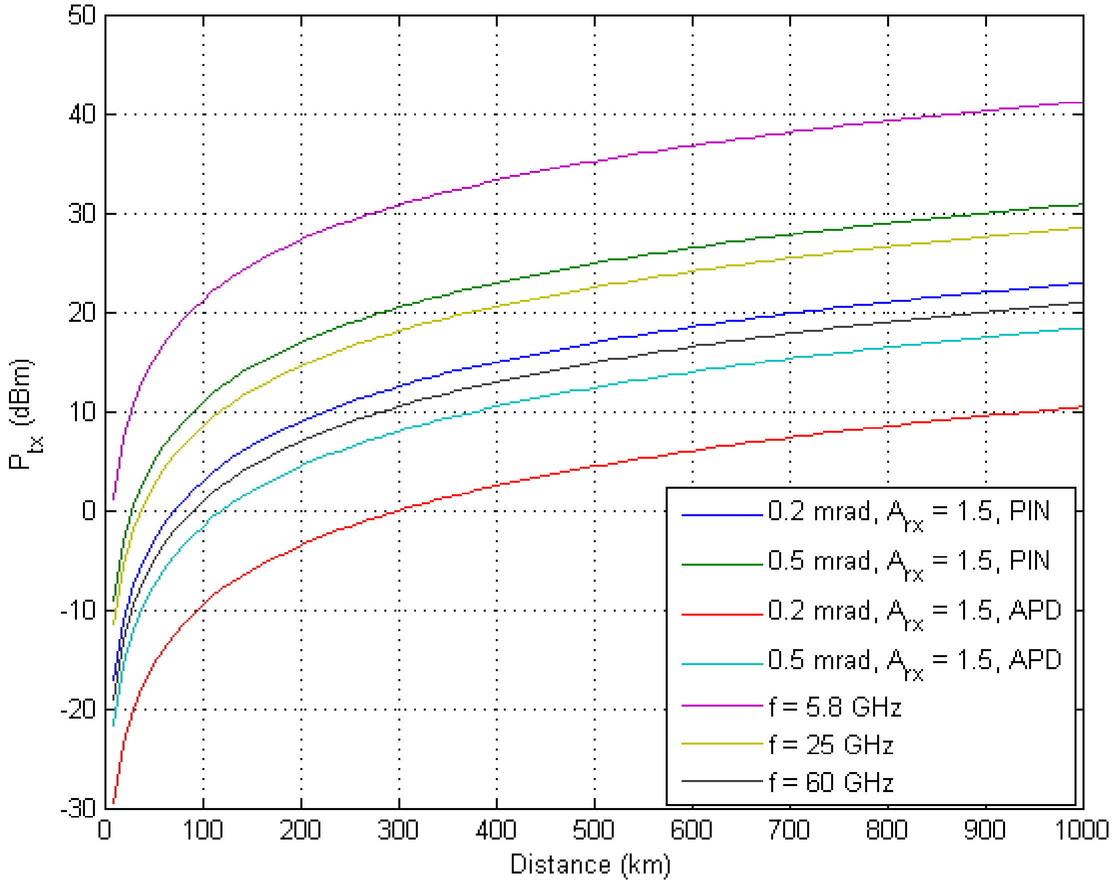

Fig. 7. Transmit power depends on the distance: optical link with different divergence angle, Rx area 119x119 cm , RF link with different frequency 120x120.

Table 8. Comparison RF and optical ISL

	Optical ISL	**RF ISL**
Transmit power, W	1 W	1 W
Receiver power, dBm	74x74 mrad: -40.1 75x75 mrad: -48	a) -88.2 b) -75.5 c) -67.9
Required receiver sensitivity (more precise), dBm	PIN: -52.9 APD: -65.5	-102

According to the Table 8 we can see, that the optical results are better than the one RF case with $f = 5.8GHz$. However, it should be taken into account, that the RF system has greater margin in all cases.

9. Conclusion

In the paper two types ISL between CubeSats satellites have been considered. RF link is the most common and the most investigated type of sat-to-sat communication. Therefore, now we have deep and extensive background and more opportunities for new research in that sphere. There are a lot of research groups and investigations which directed to extending possibilities of CubeSat formats. The main improvements are in antenna design and its parameters (increasing the frequency, decreasing the mass, dimensions and power consumption), stabilization system and pointing accuracy, solar panels.

Nevertheless, the interest in possibilities of optical communication is increasing. Such type of communication promise higher data rate and reduction mass and dimensions of the equipment. However, when we have so strong restrictions, we cannot achieve good results. Due to format constrains we need to decrease the diameters of the receivers which is caused smaller received area and communication pointing must be more precise. Additionally, many vibrations are exist in satellite system and they have a great influence to the stabilization and therefore to the pointing, acquisition and tracking.

To conclude, the most difficult issues in optical ISL, especially, in CubeSat format, are possibilities to implement so precise PAT and stabilization system. However, the power consumption in some cases are lower compared to the RF cases. For the RF ISL we do not have such problems.

Finally, the most appropriate type of ISL within power, mass and dimensions limits is RF. Optical ISL can be appropriate in large and big satellite systems.

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For citation:
Zlata Gibalina, Vladimir Fadeev. Optical Inter-Satellite Link in Comparison with RF case in CubeSat system. *Zhurnal Radioelektroniki - Journal of Radio Electronics*. 2017. No. 10. Available at http://jre.cplire.ru/jre/oct17/6/text.pdf.