Space Laser Communication Systems for Applications in Defense

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Abstract: Nowadays the use of satellites is essential in everyday life affecting many areas of our society. Given the importance of satellite systems, their development is a great priority for the scientific community, namely to support the development of more efficient and powerful communication systems. Currently, the majority of inter-satellites communications and between the satellite and ground stations uses the radiofrequency bands (RF). The free space optical communications are emerging as an alternative, providing, among other advantages, a much larger bandwidth, which is necessary to deal with increasingly larger amounts of data. The future of satellite communications will then be strongly dependent on developments in optical communication systems. In this paper will be considered the main characteristics of these systems, as well the block diagram corresponding to these communication systems. It will be done some tests using a simulator developed on this work.

Key-words: Communication systems, lasers, optical communications, radiofrequency, satellites.

I. Introduction

Satellite communication systems have evolved significantly over the last decade and currently are a key element in modern communication systems. With the growth on demand for services, particularly for mobile communication services, television and Internet, these communication systems are in continuous progress. There for, substantial investments are being made, at governmental and particular level, to respond to the ongoing developments in this area [1].

In Defense, satellite communications play a key role. On the military aspect, the ability to obtain information in time about the enemy and the theater of operations, is vital to fulfil the missions. In this kind of activities, the use of satellites allows navigation of the military forces and the achievement of images for the reconnaissance of the territory. It also provides communications, essential to coordination between forces on the battlefield, as well as to obtain updated weather information.

One of the great challenges of this type of communication systems is the implementation of optical components, to establish laser links with satellites. So, the need of increasingly larger bandwidths becomes essential the development of optical communication systems, in ground and space. Although some optical communication systems are being used, its development is still at an early stage, so the large scale use is not yet a reality [1], [2], [3].

Compared to RF links, optical links offer numerous advantages [4], [5], [6]:

- greater bandwidth and the possibility of higher data rates (in the order of Gbps);
- smaller terminal size and weight;
- do not require licenses for its implementation (in RF licenses are required due to the request transmission frequencies);
- lower power consumption of the antennas;
- greater security and resistance to interference (due to the smaller beam width and higher directivity);
- higher power received at the receiver.

The analysis of this kind of systems is the objective of this work.

II. Inter-satellite Optical Communication System

In Fig. 1 is shown a traditional optical communication system involving LEO[1] and GEO satellites and a ground station. The link between satellites is established by laser, while the link between GEO satellite and ground station can be optical or by RF. In the satellite and ground station link situation it is necessary to determine if the optical link between satellite and Earth is possible, due to attenuation in the atmosphere and beam precision between the satellite and the base station. The reason why GEO satellite is used to communicate with the ground station is its stationary regime which facilitates the communication between them. The use of LEO and GEO satellites is important because of their functions (Earth

[1] Types of Orbits: LEO (200-2000 km), MEO (2000-35780 km), GEO (35780 km) and HEO (>35780 km).

observation, communications, scientific and military missions) and through the implementation of optical links that guaranties faster and safer information transfer [7].

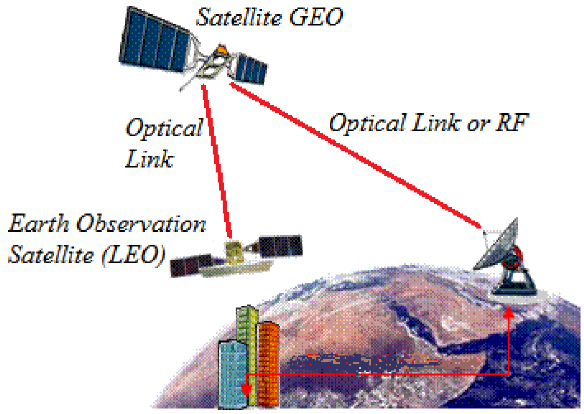

Fig. 1 - Optical communication system representation [7].

The characteristics of the environment involving satellites are influenced by its altitude. An aspect that should be considered is the Earth's atmosphere. The Earth's atmosphere disrupts the light propagation and its effects should be considered. These effects are shown in particular in Earth-satellite links (or vise versa) because the optical beam surpasses the atmosphere. There are three most relevant atmospheric effects that affect the propagation of the optical beam: geometric attenuation, atmospheric attenuation and atmospheric turbulence. The geometric attenuation consists in the increasing divergence of the optical beam during its propagation due to diffraction. With this divergence only part of the beam energy is focused and captured in the reception area of the optical antenna. The atmospheric attenuation is caused by the absorption and dispersion of the beam energy due to its interaction with the various particles present in the atmosphere, such as molecules (water vapor, carbon dioxide, ozone, etc), water drops and suspended particles (dusts). Finally, the atmospheric turbulence results from the changes in the atmospheric refractive index due to the temperature changes. These variations causes losses by beam deformation, due to random deviations in its trajectory during its propagation.

However, in inter-satellite links, that usually are performed above 100 km of altitude, the atmospheric effects are not remarkable, and therefore, it is considered that the beam propagation channel is free space [2], [3].

The distance of this links is typically in the order of thousands of kilometers, where the most common are located around 40000 km. However, there are technologies for distances greater than 40000 km. For this distances, only with optical links can be established links with bitrates around Gbps. Note that with the increase of the distance link, the power level demanded to the transmitter is higher and it is harder to point with precision the optical beam from the transmitter to the receiver.

Then, the implementation of this type of links requires a set of specifications, which are:

- the laser use for optical source: the narrow and coherent beam ensures a lower degradation;
- transmitted power: generally reaches several hundred milliwatts, reaching until 10 W, depending on the needs and characteristics of the link;
- minimum power at the receiver: receiver requires a minimal power around nanowatts. This power is related to the sensitivity of the optical receivers;
- PAT (Pointing, Acquisition and Tracking) systems: allows pointing the laser beam with precision to the receiver, establish communication and follow its trajectory. They are essential to the success of these links;
- reliability of electronic devices in space environment: the space environment in which they are inserted has high levels of radiation and extreme temperature ranges. The electronic devices incorporated in the satellites have to ensure reliability, because the maintenance and/or replacing them is very difficult (if possible) and has high costs. Therefore, there are mainly three ways to make an immune system or, at least, increase its robustness to these adverse conditions: redundant circuits, the use of shields and building electronic circuits with more resistant materials or techniques.

III. Block Diagram

An optical communication system is composed by a transmitter system, a receiver, and a signal propagation channel, which depends on the type of link that can be air or free space. However, in the optical inter-satellite links it is considered that the propagation channel is free space.

Typically, the function of the optical transmitter is to convert an electrical signal (which encodes information to be transmitted) in an optical signal, which will be responsible for transmitting data to the receiver. The receiver converts the information of optical domain to the electrical domain and also has the function of processing correctly the electrical signal in order to recover the transmitted information with minimum error as possible.

The Fig. 2 presents the standard block diagram of the optical communication system.

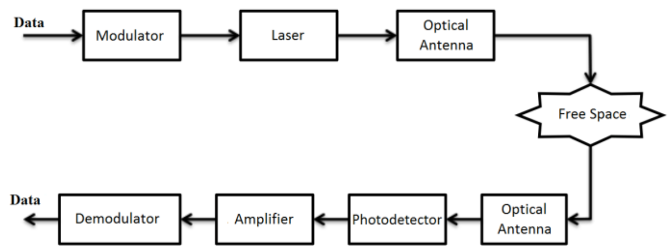

Fig. 2 - Optical communication system block diagram [5], [8].

A. Modulator/Demodulator – Modulation techniques

The modulation and demodulation are executed in the electrical domain. The modulator operates in the signal emitted by the laser, converting the transmitted data in an established standardized format [9].

This paper analyzes two modulation techniques: On-Off Keying (OOK) and Pulse Position Modulation (PPM). They are characterized by simple techniques with high reliability and with low implementation costs.

1) On-Off Keying (OOK)

The OOK modulation may be considered as a special case of amplitude modulation. As can be seen in Fig. 3, it consists in a binary technique where each time slot, T_s, corresponds to one bit. The bit "1" is indicated by the presence of a laser pulse, while the bit "0" is indicated by the absence of signal. The pulses have to necessarily be unipolar, the NRZ type (Non-Return-to-Zero), that is, the pulse duration has the same bit period, or RZ (Return-to-Zero) in which the pulse has a less duration than the bit period. Typically, the NRZ pulses are mostly used because are simpler and require less bandwidth photodetector [10]. For this reason, in this work will be considered NRZ pulses.

In the demodulation process it is the receiver that checks if at every T_s seconds is reached a signal "0" or "1" [8].

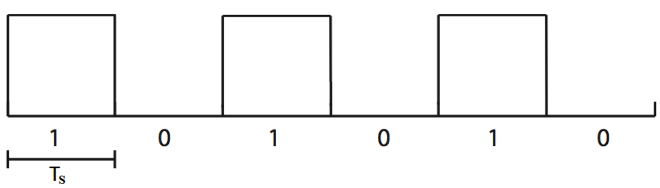

Fig. 3 – OOK signal for NRZ pulses [8].

The time slot, T_s, can be calculated by the following equation:

$$T_s = 1 / D_b \tag{1}$$

where D_b is the bitrate (bps).

In Fig. 4 are defined power levels of the laser signal. Note that the "0" bit power (P_{min}), does not correspond to a null power. Then, it is not applied $P_{max} = 2P_{med}$.

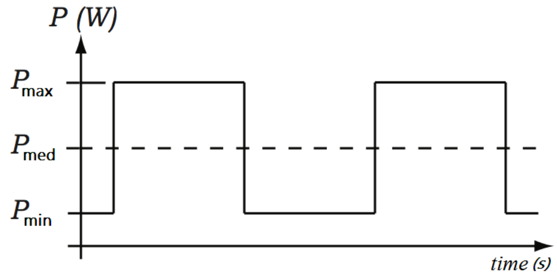

Fig. 4 –Laser signal power levels [8].

So, the ratio between maximum power, P_{max}, and the minimum power, P_{min}, is called the extinction ratio and is given by [11]:

$$r = \frac{P_{min}}{P_{max}} \tag{2}$$

where $P_{min} < P_{max}$, varying the extinction ratio between $0 < r < 1$.

At the same time, the maximum and minimum power can be also obtained from the average power, P_{med}, and the extinction ratio, r [12]:

$$P_{max} = \frac{2P_{med}}{1+r}; \quad P_{min} = \frac{2P_{med}}{1+r} \times r \tag{3}$$

2) Pulse Position Modulation (PPM)

PPM modulation consists in dividing the transmission allocated time of a symbol in m equal time slots (m is the modulation order). To represent a certain symbol, a pulse is sent only in one the m slots, as shown in Fig. 5.

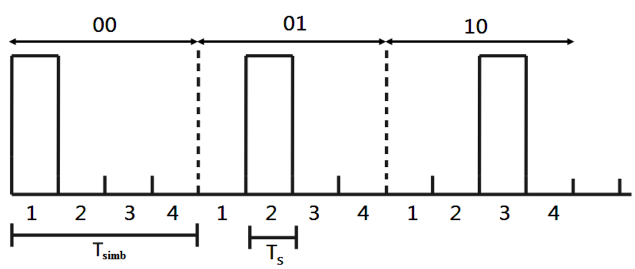

Fig. 5 - 4-PPM Signal [8].

The number of time slots, m, depends on the number of bits sent per symbol, k:

$$m = 2^k \tag{4}$$

The symbol duration, T_{simb}, depends on the bitrate D_b, and is given by:

$$T_{simb} = \frac{k}{D_b} \tag{5}$$

And the duration of the slot, T_s :

$$T_s = \frac{T_{simb}}{m} = \frac{k}{mD_b} \tag{6}$$

B. Optical Source: Laser

The main component of the optical transmitter is the optical source which generates the light radiation. There are different types of light sources which can be used for optical communications, such as LED's (Light Emitting Diodes) or lasers. Currently, there are the RCLED (resonant-cavity LED), which are based on conventional LED's, but due to some changes in its structure improvements have been made in emitted light beam, because it ensures greater directionality and intensity [13].

In the majority of satellite intercommunication systems is used the laser as a light source, due to the long communication distances. At these distances are associated high levels of attenuation and only lasers have the capacity to establish efficient links due to its specific characteristics: the emission of monochromatic radiation (wavelength well defined) and narrow and highly directive light beam. These characteristics are essential to ensure greater safety and less degradation of the beam, as well as reduce its temporal dispersion, facilitating modulation at high data rates [9], [14].

There are numerous types of lasers which classification varies according to the material that constitutes it. Currently, solid-state lasers are the most used in space optical communications. Because of its characteristics, more compact design and greater energy efficiency in converting electricity supplied into light energy, enabling to establish links at distances greater than 40000 km. In solid-state lasers, the most widely used in this kind of links are the semiconductor lasers (also called laser diodes) and crystal lasers.

The type of laser is chosen according to the characteristics of the link that is implemented, such as distance, altitude, the environmental conditions (with many losses or not) and the power level required in the receiver. It also depends on the wavelength chosen for the link as well as the implemented modulation format. In Table I are presented some examples of solid-state lasers used in optical inter-satellite links.

TABLE I
SOLID-STATE LASERS EXAMPLES USED IN OPTICAL INTER-SATELLITES LINKS.

Laser	Type	Link	Wavelength (nm)
Aluminium Gallium Arsenide (AlGaAs)	Semiconductor	ARTEMIS – SPOT-4 (2001)	800
Nd:YAG[2]	Crystal	NFIRE – TerraSAR-X (2008)	1064
Nd:YAG	Crystal	Alphasat – Sentinel-2A (2012)	1064

C. Optical antennas

In these communication systems, to transmit and receive laser beam, optical antennas are used. These antennas are used to collect and focus light, particularly in visible spectrum.

There are three primary types of antennas: refractors (dioptrics) which use lenses, reflectors (catoptrics) which use mirrors and combining lens-mirror systems (catadioptrics) which use lenses and mirrors in combination. The last one are most used in optical communication systems.

Typically, an optical antenna has an associated gain. The gain of optical antenna (in linear units) is given by the following equation [15]:

$$G = \left(\frac{\pi d_a}{\lambda} \right)^2 \times \eta \tag{7}$$

where d_a is the equivalent aperture of optical antenna, η is the efficiency and λ is the wavelength.

D. Photodetector

The photodetector is the element of the optical receiver in charge to convert the optical signal in electrical signal through the photoelectric effect.

Despite the diversity of photodetectors (photomultiplier, pyroelectric detectors, photoconductors, phototransistors and photodiodes), in optical communications are used almost always the photodiodes. That is because they have the best characteristics, that is, small sized, high sensitivity and low cost [10], [14].

There are two types of photodiodes used in the most optical communication systems: the pin photodiode and APD (Avalanche Photodiode) [14].

[2] Nd:YAG (Neodymium-doped Yttrium Aluminium Garnet) is a crystal that is used for solid-state lasers.

1) *Pin photodiode*

The pin photodiode has the structure of a p-n junction, separated by a lightly doped intrinsic region. The photodiode is reverse biased so that in the region with greater resistance, the intrinsic region, there is an intensive electric field and where almost does not exist mobile carriers, electrons and holes [10], [14].

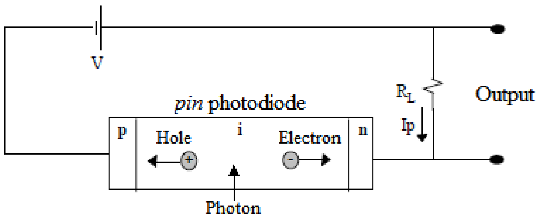

Fig. 6 - Pin photodiode reverse bias representation [14].

As shown in Fig. 6, when a photon focuses on the depletion region with an energy higher than the energy gap between the semiconductor bands used, they will excite an electron from the valence band to the conduction band. As a result, free electron-hole pairs are generated. Given the intense electric field present in the depletion region, free electrons move to the region "n" and the holes move to the region "p" before their recombination. This charge flow causes the appearance of the current, I_p normally called photocurrent.

A photodiode characteristic parameter is the responsivity, which defines the performance of the photodiode. The responsivity is the relationship between the generated current and the optical power incident on the photodiode [14]:

$$R_0 = I_p / P_i \tag{8}$$

where P_i is the optical power incident on the photodetector.

2) *APD photodetector*

The APD photodiode has the capability to amplify the internal current generated in fotodetection. It differs from the PIN photodiode because it needs higher bias voltages to achieve the desired operation. As can be seen in Fig. 7, the APD is constructed to include a very high electric field region, designated avalanche region. The avalanche region corresponds to the zone where the electric field is greater than the minimum required, E_m, to cause breakdown of the n^+-p junction and to allow signal amplification [10].

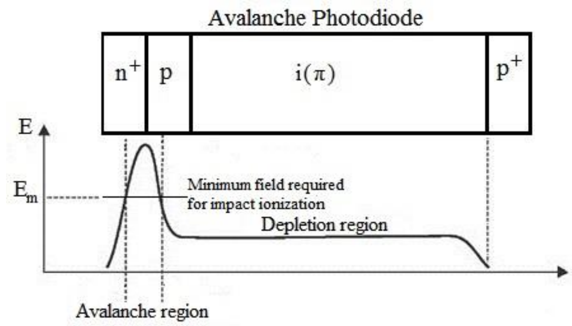

Fig. 7 – An APD together with the eletric-field distribution inside various layers under reverse bias [14].

Such as the pin photodiode, the APD performance is characterized by its responsivity, R_{APD}, which expresses the relationship between APD output current and the optical power incident on the avalanche photodiode. The relationship between the APD responsivity and responsivity to the primary current is given by [14]:

$$R_{APD} = MR_0 \tag{9}$$

where M is the avalanche gain.

3) *Photodetection noise*

Ideally, the electrical current generated by the photodetector is directly proportional to the incident optical power. However, this current have fluctuations, even when the incident power is constant. These fluctuations are caused by several types of noise. The most relevant and that will be discussed are the quantum noise and circuit noise [14].

a) *Quantum noise*

An incident optical signal on the photodetector, with a given optical power, corresponds to a certain average number of photons per unit of time. However, the time slot between photons is a random variable and the photocurrent generated by the photodiode is not a continuous process. Besides, the ptotodetector generates a small current in the absence of any optical signal. This current is called dark current, I_d, and is originated from thermally generated electron-hole pairs. The contribution of this current can be included in the quantum noise photodiode.

The photodiode quantum noise current variance is defined by:

$$\sigma_q^2 = 2q(R_0 P_i + I_d)M^2 M^x B_{e,n} \tag{10}$$

where q is the electron charge, M is the avalanche gain (in the case of pin photodiode, $M = 1$), x is a photodiode material parameter, with values between “0” and “1” , and is the equivalent noise bandwidth from the optical receiver.

b) Circuit noise

The circuit noise comes from the resistive and active elements present in the optical receiver. So, its value depends on the remaining electrical elements of the receiver such as the amplifier. For this reason, this type of noise will be discussed in the next section.

E. Electrical Amplifier

Normally, the photodetector output signal is so weak that needs to be amplified, thereby it can be properly processed by other system devices. Then, the electric amplifiers can amplify the low levels of transmitted electrical current by the photodetectors, so its signal can be read.

An amplifier must have the following characteristics: low noise, high gain and adequate bandwidth. Since the noise increases with the bandwidth, these two parameters have to be carefully taken into account to optimize the performance of the receiver. [10].

As mentioned above, the electrical components, which constitute the amplification circuit, also contribute to circuit noise. Besides, the amplifier gain also interferes in the system circuit noise. So, circuit noise current variance, σ_c^2 , is given by [12]:

$$\sigma_c^2 = \left[\sqrt{S_c(f)} \right]^2 B_{e,n} G_A^2 \tag{11}$$

where G_A is the amplifier gain, that corresponds to the value of the amplification circuit transfer function for the null frequency, that is, $H_A(f = 0)$ and:

$$\sqrt{S_c(f)} = \sqrt{\frac{4 k_B T}{R_L} F_n} \tag{12}$$

where k_B is the Boltzmann constant, T is the absolute temperature (Kelvin), R_L is the load resistance of the photodetector and F_n is the amplifier noise factor.

The square root of the power spectrum density of the circuit noise power, $\sqrt{S_c(f)}$, are $A/\sqrt{Hz}$. The typical values are in the order of 1 $pA/\sqrt{Hz}$ [12].

So, the total noise current variance, σ_n^2, is obtained from the sum of the different noise variances mentioned above [12]:

$$\sigma_n^2 = \sigma_q^2 + \sigma_c^2 \tag{13}$$

IV. Signal Power Budget and Bit-Error Rate (BER)

A. Signal Power Budget

The signal power budget have the objective to estimate the optical received power at the receiver. It is considered all the gains and losses involved in the communication process, that is, transmitter, receiver and signal propagation channel. Thus, in the optical communication system analysis, the following factors will be considered: optical transmitted power, antenna gains (emission and reception) and attenuation in free space. For simulation purposes it will be considered that the emitted laser beam is perfectly coincident with the receiving surface and therefore it will be despised the pointing losses. The receiver power (dBm) is given by [8], [16]:

$$P_{r_{dBm}} = P_{t_{dBm}} + G_{t_{dB}} - L_{s_{dB}} + G_{r_{dB}} \tag{14}$$

where P_t is the normalized average optical power at 1 mW, G_t and G_r the gains of the transmit and receive antennas, respectively, and L_s free space losses.

The free space losses are given by:

$$L_{s_{dB}} = 20 \log \left(\frac{4 \pi d}{\lambda} \right) \tag{15}$$

where λ is the wavelength and d is the distance between satellites.

B. Bit-Error Rate

The optical receiver performance of a digital transmission system is measured by BER (Bit-Error Rate). This parameter is defined as the ratio between the number of incorrect bits received by the total number of bits transferred in a given time interval. Typically, in this kind of communication systems the BER should be below 10^{-6}, and the typical values are between 10^{-6} e 10^{-9} [17].

1) BER – OOK Modulation

For OOK modulation, BER can be calculated by the following equation *[11]*:

$$BER_{OOK} = \frac{1}{2} erfc \left(\frac{Q}{\sqrt{2}} \right) \tag{16}$$

where Q parameter is given by:

$$Q = \frac{V_1 - V_0}{\sigma_1 + \sigma_0} \tag{17}$$

which V_0 and V_1 are the values of the voltages logic levels "0" and "1" and σ_0 and σ_1 are the squared root of the noise variances to symbols "0" and "1", respectively, obtained individualizing the expression (13) for the optical power for the symbols "0" and "1". The $erfc$ function is the complementary error function, defined as:

$$erfc(x) = \frac{2}{\sqrt{\pi}} \int_{x}^{+\infty} \exp\left(-y^2\right) dy \quad (18)$$

2) BER – PPM Modulation

As already mentioned, this modulation technique is more complex than OOK, since several bits are sent in an impulse. It is necessary a rigorous synchronization with the start of each symbol by the receiver. Thus, the receiver, in the decoding process, it must choose the correct time interval, which in theory will be the highest intensity pulse. However, if the receiver decode the wrong interval, the number of bit errors it will be $\leq k$. The average number of wrong bits by decision errors, is given by:

$$N_{be} = \frac{m}{2(m-1)} \quad (19)$$

where m is the modulation order.

The receiver probability to choose the correct time interval is represented by the following expression [8]:

$$P_{csc} = \int_{-\infty}^{\infty} \frac{1}{\sqrt{2\pi}\sigma_1} e^{-\frac{(x-V_1)^2}{2\sigma_1^2}} \left[\int_{-\infty}^{x} \frac{1}{\sqrt{2\pi}\sigma_0} e^{-\frac{(y-V_0)^2}{2\sigma_0^2}} dy \right]^{m-1} dx \quad (20)$$

Based on the expressions (19) and (20), the BER for PPM modulation is defined by [8]:

$$BER_{PPM} = N_{be}\left(1 - P_{csc}\right) \quad (21)$$

V. Tests and Results

In this section will be performed several practical examples using the simulator developed with the goal of analyzing and comparing the system performance in different situations.

A. Simulation of increased distance

This example will be based on data from an optical link held in 2008 between two LEO satellites: NFIRE e TerraSAR-X [18].

The data used in the simulator were:

TABLE II
PARAMETERS INSERTED IN THE SIMULATOR [18].

Parameters	Values
P_t (Transmitted Power)	0.7 W
D_b (Bitrate)	5.6 Gbit/s
λ (Optical Wavelength)	1064 nm
r (Extinction Ratio)	0.152
d_{at} e d_{ar} (Aperture Diameter)	12.4 cm
η_t e η_r (Optical Antenna Efficiency)	0.8
Modulation	OOK
Photodiode	APD
R_0 (Responsivity)	0.6 A/W
M (Avalanche Gain)	40
I_d (Dark Current)	5 nA
$B_{e,n}$ (Equivalent Noise Bandwidth)	10 GHz
$\sqrt{S_c(f)}$ (Square root of the PSD of the circuit noise power)	5p $A/\sqrt{Hz}$
G_A (Amplification Gain)	50 dB

With these values, there were several simulations with different distances. The results are in Table III.

TABLE III
RESULTS OBTAINED IN FUNCTION OF THE DISTANCE VARIATION.

	Results				
d (km)	P_r[dBm]	BER	SNR' [dB]	$\sigma_c^2[V^2]$	$\sigma_q^2[V^2]$
5000	-26.37	$1.02*10^{-21}$	18.82	$2.5*10^{-8}$	$2.15*10^{-6}$
10000	-32.40	$2.11*10^{-6}$	12.60	$2.5*10^{-8}$	$5.43*10^{-7}$
15000	-35.92	0.001	8.78	$2.5*10^{-8}$	$2.46*10^{-7}$
20000	-38.42	0.02	5.89	$2.5*10^{-8}$	$1.42*10^{-7}$
25000	-40.35	0.06	3.50	$2.5*10^{-8}$	$9.36*10^{-8}$
30000	-41.94	0.11	1.41	$2.5*10^{-8}$	$6.73*10^{-8}$
35000	-43.28	0.16	-0.45	$2.5*10^{-8}$	$5.15*10^{-8}$
40000	-44.44	0.21	-2.15	$2.5*10^{-8}$	$4.12*10^{-8}$

With the results obtained in the table, it possible to see that there is a significant increase in the BER with increasing link distance. It should be noted that the BER requirement is largely accomplished for the initial distance (5000 km), but from 15000 km, with these parameters, the link is not viable. The received power and signal-to-noise ratio follows, as expected, the increase of BER. The circuit noise remained constant, because it did not change the noise parameters of the electrical elements. However, quantum noise decreased with increasing distance, since this type of noise depends on the received power. So, if the received power was decreasing, the quantum noise followed this decay.

B. Simulation with different modulation types

In this example the data are about an optical link held in 2012 between an LEO satellite and another GEO: AlphaSat and Sentinel 2-A [18].

The data used in the simulator were:

TABLE IV
PARAMETERS INSERTED IN THE SIMULATOR [18].

Parameters	Values
P_t (Transmitted Power)	5 W
D_b (Bitrate)	2.8 Gbit/s
λ (Optical Wavelength)	1064 nm
r (Extinction Ratio)	0.152
d_{at} e d_{ar} (Aperture Diameter)	13.5 cm
η_t e η_r (Optical Antenna Efficiency)	0.8
d (Distance)	45000 km

The receiver parameters remained the same as in the previous example. In **Erro! A origem da referência não foi encontrada.** V are shown the BER results according to the selected modulation format.

TABLE V
BER DEPENDING ON THE TYPE OF MODULATION.

Modulation Format	BER
OOK	$9.09*10^{-4}$
2-PPM	$1.76*10^{-4}$
4-PPM	$1.19*10^{-4}$
8-PPM	$7.81*10^{-5}$
16-PPM	$4.96*10^{-5}$
32-PPM	$3.04*10^{-5}$
64-PPM	$1.80*10^{-5}$

The objective of this simulation is to compare system performance with the different modulation types. From the results obtained, it is concluded that the OOK modulation has the worst performance. In the other side, it appears that the greater the PPM modulation order, the better is the BER performance. However, the performance improvements are not very significant with the increases the modulation order. Therefore, in most cases, the performance improvement obtained does not compensate the increase of the system complexity. Traditionally, it is for this reason that the modulation order used is 2 (2-PPM).

VI. Conclusion

Taking into account the growing importance of the optical communications to commercial and military level, this work aimed to analyze a satellite intercommunication system using lasers. The study has identified the transmitter and receiver subsystems and analyzed the main characteristics associated with these communication systems. Allied to this study, it was also developed a program that allows the simulation of optical inter-satellite links. The simulator allows to establish good approximations for this links and to change various parameters.

The development of this kind of links arises due to the higher bandwidth requirements caused by the increase of traffic in telecommunications networks and the Internet. Thus, the need of increasingly larger bandwidths, becomes essential to the development of optical communication systems, in ground and space.

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