Selection of optimal settings depending on the FSO system parameters.

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Abstract
During the past years FSO systems are increasingly used in modern communication systems. They are used as part of local networks, for Backhaul, they are very perspective in solving the issue with low information bandwidth towards the end user. However these systems have number of issues which have to be resolved. Some of them can be overcome by appropriate selection of system parameters.

This paper represent developement of free space optics system. The report provides an optimum choice of divergence of laser transmitter according to the power source of optical radiation and the length of the channel. Solved are specific issues related to the selection of the element basis for building the system depending on the scheme of work and parameters specified. There is a synthesized scheme of experimental stand for measuring of BER of system working at various configurations and conditions. Produced are experimental checks in lab conditions, confirming the characteristics of the individual parts of the system.

1. Connection between divergence of the optical beam and bit error rate

Here we will focus our efforts on practical analysis of the dependence of the maximum angle of divergence (resp. radius of the beam in the receiving aperture), in which we are still required for proper operation of the receiver power (BER $<\text{BER}_{\text{max}}$).

In considering accepting to work with Gaussian laser beam [1], etc. radial dependence of the optical radiation at a distance $z$ from the transmitting antenna is

$$I(\rho, z) = I(0, z) I_n(\rho, z)$$  \hspace{1cm} (1)

, where $I(0, z)$ is the intensity of optical radiation along the axis of the beam and

$$I_n(\rho, z) = \exp \left( -2 \frac{\rho^2}{\rho_0^2(z)} \right)$$  \hspace{1cm} (2)

is the normalized intensity of the radiation diagram. Current radius of Gaussian laser beam is given by expression

$$\rho_0(z) = \rho_0 \sqrt{1 + \frac{4z^2}{k^2\rho_0^4}}$$  \hspace{1cm} (3)

where $\rho_0$ is the initial radius and $k = \frac{2\pi}{\lambda}$ is the wave number.

By modifying $\rho_0$ in (3), which is achieved by changing the distances between optical elements in the collimator, we get different spatial distributions of power density of laser radiation in a plane transverse to the axis of the beam in Fraunhofer zone (Fig. 1).

![Fig.1. Different spatial distributions of density power laser radiation in a plane transverse to the axis of the beam.](image)

With the reduction of $\rho_0$ (at constant transmitted power of the laser) at first $\rho_{\text{max}}$ increase, but after a specified value begins to decrease. In Figure 1 with the horizontal level $I_{\text{min}} = I(\rho_{\text{max}}, z)$ is marked the intensity of radiation, in which the optical flow aperture of the photodetector corresponds to the specified maximum error rate $\text{BER}_{\text{max}}$, i.e.

$$\Phi_{\text{PD, min}} = \Phi_{\text{PD}}(\text{BER}_{\text{max}})$$

By realization of a condition (respectively, solve the equation)
\[ \Phi_{PD}(\rho_{\text{max}}) = \Phi_{PD,\text{min}} \]  

we reach the dependence

\[
\rho_{\text{max}}(\rho_{0}, \tau, z) = \left( \frac{1}{2} \ln \left[ \frac{2\pi \tau \tau_{c} K^{2} \Phi_{\text{in}}}{\rho_{0}^{2}(\rho_{0}, \tau, z) \left[ 1 - \exp(-2) \right] \Phi_{PD,\text{min}}} \right] \right)^{1/2}
\]  

\( 5 \)

2. Hardware

Different stages in the development of the system can be determined by individual blocks. Fig. 2 shows the block diagram of our system. It consists of two sets, each including a receiving unit RX, transmitting unit TX and combining digital module. Optical beam is focused be optical system. We worked on tune optical system.

We use schemes that provide distance, speed, and bit error rate. Generally speaking, optical wireless system can be divided into three parts - a reception module transmission module and digital circuit that combines the two modules.

2.1. Functional-block diagram of the transmitter of optical radiation

The principal scheme of the transmitter is shown in Figure 5. It also consists of three stages. The first stage is impedance matching stage. It connects the output of the transmitter with digital module. The second and third stages are driver stage and final stage, direct managing source of optical radiation.

The last two steps are designed with integrated circuits 74HC07, as an appropriate number of logic elements connected in parallel.

2.2. Functional-block diagram of the receiver of optical radiation

Figure 4 shows a principal scheme of the receiver. It consists, broadly speaking, of three stages. The signal from photodiode D1 (BPW43) is fed through the input capacitor at the first amplifier AMP1, which is implemented with MOS transistor BF961. Second stage AMP2 is realized on the basis of operational amplifier TL026. The third stage is used for impedance matching between output of AMP2 and the input of digital module.

2.3. Functional-block diagram of the digital scheme

Fig. 6 shows a functional-block diagram of digital circuit, which aims to make the connection between the RX-TX kit and PC. There is also function to keep the connection "alive" when the information is not transmitted. That scheme adds also link integrity pulses to the useful signal carrying the information. The scheme can be examine as made up of two parts, transmission and reception. They work similarly. Receiving side accepts a signal from the optical receiver RX, when signal enters to the first
Block of the Receive scheme. After that block the signal splits into two blocks, block Pulse extender and block twisted pair driver. Pulse extender block determines when the packets are received at the input of the system and switch through multiplexer MUX both signals of TP Driver and block Divider. In this way the scheme adds signal integrity pulses to the IP packets. This signal is sent when the information is not transmitted through information channel in order to integrity of the link.

**Fig.6. Functional-block scheme of digital scheme**

As already mentioned in the previous paragraph, the transmission side operates similarly with the difference that does not accept the signal from the optical receiver but of a LAN network. In addition here the signal for the integrity of link differs by frequency with this in receiving side. Here, divider divide by 16 instead $2^{18}$. This produces a signal with a frequency of 1 MHz, send by the optical channel.

2.4. Experimental setup for measuring Bit Error Rate

The bit error ratio (BER) is a measure of the percentage of bits that a system does not transmit or receive correctly. It is a dimensionless number ranging from 0 to 1. If the BER = 0, then all bits are transmitted correctly at the other extreme, if the BER = 1, every bit is received in error. Every transmission system (and every part of it) has an intrinsic bit error ratio, which can take on any real number between 0 and 1. The exact value may change, for example, with temperature or operating voltage, but it’s a fundamental system property [2].

$$BER = \frac{N_{err}}{N_{all}}$$  \hspace{1cm} (6)

where $N_{err}$ - number of mistaken bits, $N_{all}$ - number of all bits. It’s very important constructed FSO system to be tested for BER in real atmospheric conditions [3, 4].

The device which is measuring the level of error BER is called BERT bit error rate tester. This article describes exactly such a scheme for measuring the BER [5].

Block diagram and real photos of the system is shown in Fig.7. The information is transmitted simultaneously on two channels one is atmospheric and the other is a conductor.

Once the information passing through both channels of their output signals are compared in the block BER measure. If there is a difference in the two signals the counter COUNTER shows an counts on the display. Since the delay of the signal varies in both channels they are connected delay elements to the scheme. Delays are implemented in two ways.

**Fig.7. Block scheme of BER measuring system**

The random number generator is realized by shift registers and logic elements exclusive OR (XOR) shown in Fig.8. The information is shifted on every tick of the clock generator from left to right, and last but one and last digit are connected to both inputs of the logical element XOR. After completion the logical operation result is returned to the first digit of the shift registry, etc.

**Fig.8. Scheme of random number generator**

The coarse delays of n number of ticks is implemented with D flip flops Fig.10. Depending on the required number of ticks of delay a different number of D flip flops are used [6]. For shorter delays are used non-inverting buffers.

For comparison of two signals from the optical path and conductor are used logic elements exclusive OR (XOR) Fig.11.

To avoid error in the divergence of the two fronts of the signal after XOR logic element is added a logic element AND is added, comparing the two signals only when the clock signal is in high level.
2.4. Experimental setup for measuring dependence of frequency by amplitude.

One of the most important parameters for quality reception of information without loss with optical wireless communication system are the time for transition from logical zero to logical one, time for transition from logical one to logical zero, and the amplitude of the received signal. Described experiment refers to these parameters. Scheme of the experimental setup is shown in Fig.12.

It consists of pulse generator G, transmitter of optical signal TX, environment FSO, receiver RX and oscilloscope. Frequency is changed in the range of 1Mhz to 10Mhz by 1Mhz step.

![Fig. 12. Scheme of experimental setup](image)

**Fig.12. Scheme of experimental setup**

Fig.13 shows real picture of the stand.

![Fig.12. Real picture of stand.](image)

**Fig.12. Real picture of stand.**

3. Results

This section shows experimental results from chapter 1 and 2.

### 3.1. Results from Connection between divergence of the optical beam and bit error rate

Here we will examine numerical example based on the result (5) with the parameters of system developed by us: wavelength $\lambda = 850\text{nm}$; leakage of the transmitting and receiving antenna respectively $\tau_t = 0.9$ and $\tau_r = 0.7$; visibility of the atmospheric layer with a thickness $z=1\text{km}$ $\tau_a(S_m=10\text{km}) = 0.797$; Radius of the receiving antenna $R_r = 0.025\text{m}$; $\Phi_0 = 10\text{mW}$; $\Phi_{PV, min} = 20\mu\text{W}$. Graphical results of the substitution in (5) are presented on (Fig.13).

![Fig.13. Graphical results of the substitution in (5)](image)

**Fig. 13. Graphical results of the substitution in (5)**
3.2. Results from Bit Error rate measuring system.

Fig.14 and Fig.15 shows two computer simulations. In Fig.14 can be seen an error caused by misalignment of the two edges of the pulses: the first is the transmitted data and the second is the delayed original data. In Fig.15 the signals are aligned in time at which the error does not occur. Error signal at output of the scheme is low level.

![Fig. 14. Computer simulation of error](image)

![Fig. 15. Computer simulation without error](image)

We left the system to work for a week, but the weather conditions prevented the accumulation of any error. The nominal working distance of the system is 1km, but in the particular case we worked at 180 m. This also prevents accumulation of error.

The described scheme can be applied for studying the dependence of the level of bit error of Free Space Optics systems and the dependency of destabilizing factors such as atmospheric conditions (fog, snow, rain, etc.). [7, 8].

3.3 Results from dependence of frequency by amplitude.

Research that are made with the modules are capture dependence of the frequency of the system, of the amplitude of the received signal and the times Trise and Tfall. Table 1 shows numerical values for the amplitude of the received signal, while fig. 16 shows a graph. Fig.17 shows graph of Trise, Tfall against frequency. Fig.18 shows conditions of measuring Trise and Tfall.

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![Tabl.1](image)
Conclusion

In Bulgaria is formed group, at present the only, which created and works on improving of FSO. The aims of our work are the creation of our unique communication system and solve some theoretical issues related to divergence of optical radiation, BER, information speed and working distance.

Bibliography

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