Research on the rise time of a PIN photodiode during FSO application

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Abstract – **This paper deals with a practical research on the rise time of a PIN photodiode during the transmission of an impulse series in a function of different factors characteristic of a Free FSO factor system.**

Keywords – **Free Space Optical Systems, Rise Time, Receiver PIN Diode.**

I. INTRODUCTION

The free space optic communication systems (FSO) typically use series of impulses for the transmission of the logical states of the binary digital signal. In the transmission side there is a light emitting diode (LED) [1-4] or laser [5,6], while in the receiver side there are PIN diodes or avalanche photo diodes (APD). In the references and the respective data sheets a common approach for transfer function in the sense of [7] is usually referred to. In many cases of optical systems with relatively determined characteristics of the propagation medium and the geometrical locations of the transmitter and the receiver, this is sufficient. An example of this are the fiber optic systems. However, this is not the case of the FSO systems, where a strong fluctuation of the atmosphere transparency as well as spot movements in the receiver plane are observed [8].

II. GENERAL SETTING OF THE ANALYSIS

The physical parameters of the FSO systems [1-4] are relatively weakly determined. It turns out that the significant changes of the intensity of the optical radiation in the receiver aperture are one of their major problems [8]. The contemporary systems operate at extremely high speeds and, of course, the goal is to reach even higher ones at relatively long distances. With a changing intensity, this problem is sufficiently difficult to be worth solving.

The performance of a FSO link is primarily dependent upon the climatology and the physical characteristics of its installation location. In general, weather and installation characteristics that impair or reduce visibility also effect FSO link performance. The primary factors affecting performance include atmospheric attenuation, scintillation, window attenuation, alignment or building motion, solar interference, and line-of-sight obstructions.

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Atmospheric attenuation [9] of FSO systems is typically dominated by fog but can also be dependent upon low clouds, rain, snow, dust, and various combinations of each.

Atmospheric scintillation [10-12] can be defined as the changing of light intensities in time and space at the plane of a receiver that is detecting a signal from a transmitter located at a distance. The received signal at the detector fluctuates as a result of the thermally induced changes in the index of refraction of the air along the transmit path. These index changes cause the atmosphere to act like a series of small lenses that deflect portions of the light beam into and out of the transmit path. The time scale of these fluctuations is of the order of milliseconds, approximately equal to the time that it takes a volume of air the size of the beam to move across the path, and therefore is related to the wind speed. Scintillation can change by more than an order of magnitude during the course of a day, being the worst, or most scintillated, during midday when the temperature is the highest.

Overall, scintillation causes rapid fluctuations of received power and, in a worst case, results in high-error-rate FSO performance. However, at ranges less than 1 km, most FSO systems have enough dynamic range or margin to compensate for scintillation effects. For longer, lower-availability links, transceiver design features such as the use of multiple laser transmitters can substantially reduce the effects of scintillation.

One of the key challenges with FSO systems is maintaining transceiver alignment [1,13]. FSO transceivers transmit highly directional and narrow beams of light that must impinge upon the receive aperture of the transceiver at the opposite end of the link. A typical FSO transceiver transmits one or more beams of light, each of which is several centimeters in diameter at the transmitter and typically spreads to several meters in diameter at a range of 1 km. For a FSO link to function, it is very important that both the transmitted beam of light and the receive cone encompass the transceiver at the opposite end of the link.

Despite our perceptions to the contrary, buildings are, in fact, constantly in motion [14,15]. This movement is the result of a variety of factors, including thermal expansion, wind sway, and vibration. Because of the narrowness of the transmitted beam and the receiver's field of view (FOV), building sway can affect a FSO transceiver's alignment and interrupt communication. This building sway is generally referred to as "base motion." In most circumstances, angular motion, as opposed to linear motion, poses the greatest challenge for transceiver alignment. Base motion can usually be assigned to one of three classes: low, moderate, and high frequency. Low-frequency motion is defined as motion with periods from minutes to months and is dominated by diurnal and seasonal temperature variations. Moderate-frequency motion has periods of seconds and includes wind-induced building motion. High-frequency motion has periods of less than 1 s and is generally referred to as vibration, which includes motion induced by large machinery, as well as human activity.

Base motion can cause link outages in two ways: excess geometric loss due to pointing errors and/or large detector coupling loss due to tracking errors. Geometric loss is the optical loss from the transmit terminal output aperture to the receive terminal input aperture. Errors in the pointing of the transmit laser beam toward the opposing terminal's receive aperture (angle in link space) will increase this geometric loss. As the receive spot moves away from the center of the detector, the detector coupling loss increases. Given that the tracking error exceeds half the receive FOV, this tracking loss can increase quickly.

In the references dealt with, we did not encounter any characterization of the impulse and frequency characteristics in a function of the optical flux level change [16,17]. What is more, we did not encounter a research on these parameters in a function of the geometric location of the receiver and the transmitter. The latter is an extra difficulty because it is possible to observe radiation of different parts of the aperture of the receiver. That is, we have an accumulation of several factors. That is why we decided to focus on a methodology for an experimental research which is to a certain extent close to the actual states of an FSO system.

Due to the intrinsic layer design, most of the photons will be absorbed within the intrinsic region rather than the p- and n- layers of the outside of the structure. This drastically improves the responsivity and rise time of PIN diodes when compared to PN diodes [4]. This improvement does not, however, mean a complete removal of the inertial effects caused by not sufficiently generated carriers.

This paper deals with only with the rise time for a PIN diode. This is of course the first step and in the future we also plan to do research on APD.

By definition, the rise time is presented as the time to rise from 10 to 90% (Fig.1).

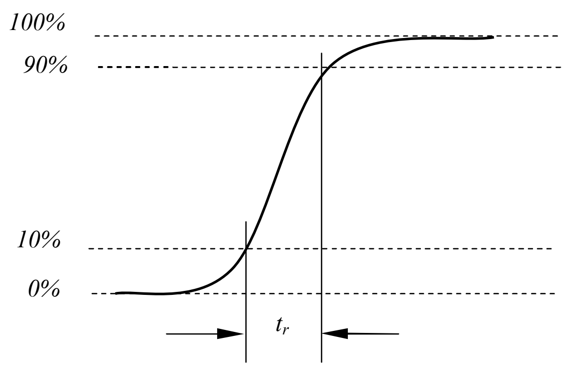


Fig. 1. Rise time

This time is related to the general productivity and during the planning it is good for us to have an idea of its dependence on different factors with a specific influence for the FSO systems.

Usually the time depends on different factors [4] Eq. (1)

$$t_r = \sqrt{t_1^2 + t_2^2 + t_3^2} \quad , \tag{1}$$

where

$t_1 \sim C_t R_L$ – time determined by the thermal capacitance and the load resistance;

t_2 – diffusion time of carriers generated outside the depletion layer; Carriers may generate outside the depletion layer when incident light misses the P-N junction and is absorbed by the surrounding area of the photodiode chip and the substrate section which is below the depletion area. The time required for these carriers to diffuse may sometimes be grater than several microseconds.

t_3 – depletion layer transition time; The transit speed at which the carrier travel in the depletion layer is expressed using the traveling rate and the electric field developed in the depletion layer.

Depending on which time is prevailing, there are specific curves in the shape of the rectangular impulse. The general increase of the time t_r of course influences the general operation of the system.

III. Experimental setup

To check the problems we make an experimental setup, described schematically on fig.2.a and with picture on fig. 2.b.

We use receiver and transmitter for laboratory experiments. For the present they do not have the highest indicators worldwide, but they are appropriate for the conducting of a research of principle. That is why in the next sections we look at normalized values for the time of relative movements.

IV. Experimental procedure for students

In this section we will present example step by step algorithm for student Lab experiment:

1.The detector and transmitter should be fixed to high precision X,Y translation and Z rotation mounts (Fig.1b).

2.The detector and transmitter should be electrically connected to amplifier and generator respectively (Fig.1a).

3.The oscilloscope should be connected to appropriate amplifier outputs.

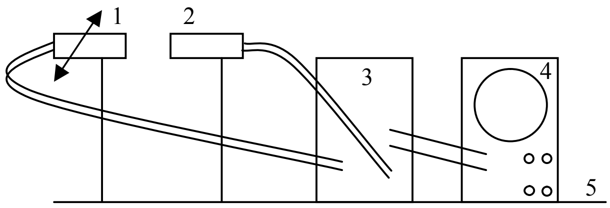
3.1.After aligning procedure oscilloscope screen should look similar to Fig.2.

3.2.The signal should be placed between 0 and 100% marks.

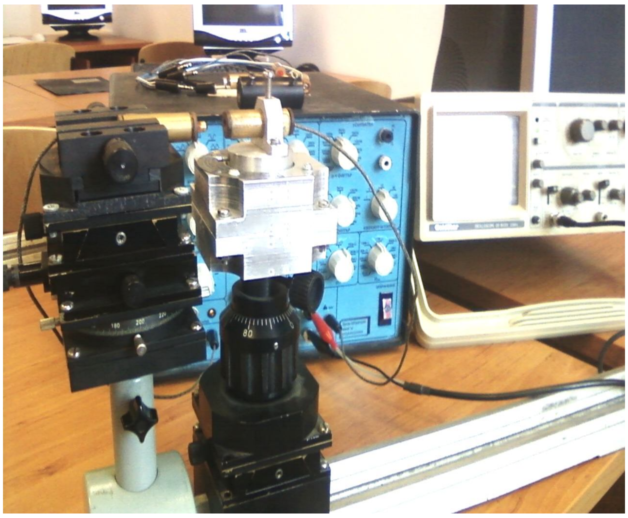
3.3.Using time control should be derived view similar to Fig. 3.

3.4.Using appropriate micrometer change one of geometrical factors of optical mount.

Repeat 3.2-3.4 until limit value for measuring was reached.



a



b

Fig. 1. Experimental setup
(1 – LED source with ability of displacement; 2 – PIN diode; 3 – generator and amplifier for blocks 1 and 2; 4 – oscilloscope; 5 – mounting;)

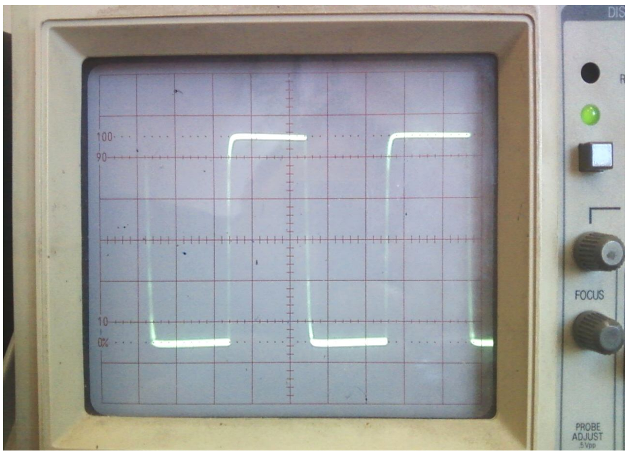


Fig. 2. Basic oscilloscope screen
(measured signal should be placed between 0 and 100% marks)

V. Experimental Results

In this section we present actual results from measurements conducted in the optoelectronics and optical communications laboratory in the Technical University Sofia (Table I). Data from Table I is plotted on fig.4. As we had expected, the results display a dependence of the rise time on the flux and also on the geometrical changes in general.

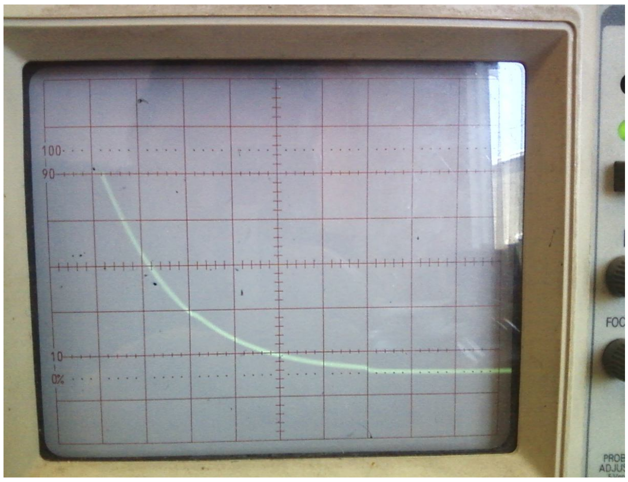


Fig. 3. Oscilloscope with fine adjusted time control settings to measure t_r

TABLE I
TIME IN FUNCTION OF DISPLACEMENT

Normalized displacement	0	1	2	3	4	5	6	7	8
Normalized time t_r	1	1	1	1	1	1	1	1,14	1,59

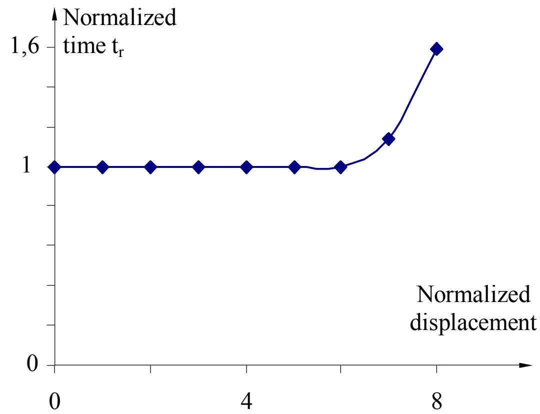


Fig. 4. Plotted experimental data from table I

VI. Conclusion

The research we have conducted can be useful for checking one more characteristic of the PIN diodes, namely the time dependency in a function of the flux intensity and also on the geometrical movement. Our work has shown that when using PIN photodiodes in a specific way under the conditions of an FSO application, the results from Eq. 1 are not sufficiently accurate. This paper would also be useful in that it provides concrete experimental guidelines.

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