Optical method for collecting and examining the dynamic range of signals by displacement of MMF

Tsvetan Valkovski[1] and Kalin Dimitrov [2]

Abstract – **In this paper, we have considered an optical method for collecting and examining signals by displacing multimode optical fibers. Attention is paid to the study of the dynamic range of these signals obtained by displacement between multimode optical fibers. The study of the dynamic range of external signals is performed by considering the losses from axial and lateral displacement. The evaluation of both types of displacements was performed in theoretical, simulation and experimental ways, and applicability in different approaches was proposed.**

Keywords – **Optoelectronics , Optoacoustic, Multimode optical fibres**

I. INTRODUCTION

The method considered in this article is based on the study of displacement losses of multimode optical fibers, and the aim is to estimate the losses from axial and lateral displacement. In classical communication systems, the goal is to minimize these losses, whether in detachable or non-detachable joints. In our study, the opposite is true - we are interested in which of the two cases we would have greater losses with less deviation, because relative to these losses we have the opportunity to report a change that represents the amplitude or so-called dynamic range of an external signal. For example, there is the nature of a sound-air pressure wave exerting a certain force on the surface of an oscillating system. This oscillating system is considered in the form of the surface of one of these fibers.

II. THEORY

An important point of consideration of the optical signal is the fiber-atmosphere-fiber relationship. The focus here is the displacement of the fiber source and the fiber receiver. In this line of thought, this connection could be described as an optical wireless system, due to the small distance between the source and receiver losses in the atmosphere and radiation costs are minimal, and the resulting losses from vibration and displacement in the optical systems of the transmitter and the receiver are of interest to us.

In the optical range, however, the diffraction propagation of radiation, and especially of quasi-monochromatic laser radiation, is accompanied by a strong and multifaceted interaction between the field and the material atmospheric environment. This is due to the following two main reasons: optical wavelengths are comparable to the size of atmospheric microforms, average frequencies of laser radiation are comparable to the centers of intense lines of absorption of atmospheric gases. Therefore, modeling the environment in which the laser radiation propagates using the notion of free space is permissible only in rare cases: at very short distances between the laser and the receiver, in a very clean atmosphere, with a mismatch of radiation frequency with atmospheric gas absorption line [1-3].

Such a special case is the variant studied by us, the optical fibers are physically separated, but close enough to each other, and here is taken into account the problem that the study of the impact in question is an extremely complicated problem that cannot be fully solved by modern atmospheric optics. Complications arise both from the properties of laser radiation (coherence, monochromaticity, directivity, intensity, and polarization) and from the great variety of specific atmospheric conditions, whose characteristics vary greatly in space and time, and their variations are subject to nonstationary and inhomogeneous (in the general case) random laws. When considering the problem, it is important to mention the inevitable energy losses caused by the permeability of the beam shown in Fig.1.

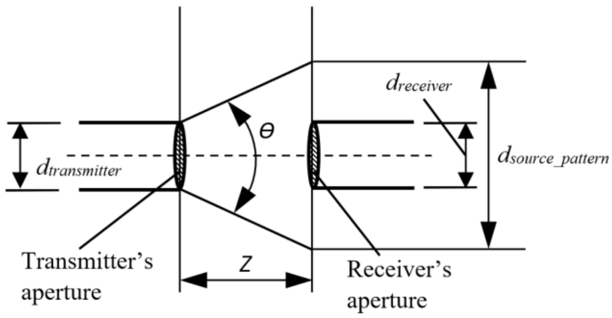


Fig. 1. General setup of an optical communication system with open transmission ambience

To partially compensate for the impact of vibrations on buildings, for example, and to facilitate the direction of the transmitter, a minimum of these losses is usually not sought, and even additional expansion of the light beam to 4-8mrad is possible.

It is possible to use a corrected version of the Gaussian laser beam propagation model [2]

$$d_{sourcepattern} = d_{transmitter}\sqrt{1 + K_\theta^2 \frac{\lambda^2 Z^2}{\pi^2 \left(d_{transmitter}/2\right)^4}} \qquad (1)$$

[1]Tsvetan Valkovski is with the Faculty of Telecommunications at Technical University of Sofia, 8 Kl. Ohridski Blvd, Sofia 1000, Bulgaria, E-mail: cvalkovski@tu-sofia.bg

[2]Kalin Dimitrov is with the Faculty of Telecommunications at Technical University of Sofia, 8 Kl. Ohridski Blvd, Sofia 1000, Bulgaria, E-mail: kld@tu-sofia.bg

Where K_θ, θ as in the previous expression, it must be specified by the manufacturer of the transmitting optics.

Using the geometric approximation that the light beam is described by a straight circular cone and that in the plane of the receiver we have close to uniform distribution, the diameter of the spot that will be formed in this plane is calculated as

$$d_{sourcepattern} = Z\theta + d_{transmitter} \tag{2}$$

Geometric losses are calculated as the ratio of the areas of the light spot designed by the source and the receiving aperture (3):

$$B_{geometic}[dB] = 10\lg \frac{S_{sourcepattern}}{S_{receiver}} \tag{3}$$

where respectively

$$S_{sourcepattern} = \left(\pi d^2_{sourcepattern}\right)/4 \tag{4}$$

and

$$S_{receiver} = \left(\pi d^2_{receiver}\right)/4 \tag{5}$$

The formulas shown above are simplified for application in this case, as they are derived from the theory of losses in FSO systems.

Geometric path loss is present for all FSO links and must always be taken into consideration in the planning of any link. This loss is a fixed value for a specific FSO deployment scenario; it does not vary with time, unlike the loss due to rain attenuation, fog etc.

Having considered the geometric optical losses, it is important to mention the options for shifting the two fibers, because in this case our optical wireless system is short distance [4-8].

There is a possibility for displacement of three parameters - mutual displacement of the longitudinal axes of the fibers in a perpendicular plane or lateral displacement *d*; distance between the foreheads of the fibers or axial displacement *t*; angular displacement between the longitudinal axes of the fibers or angular displacement φ. The three cases are shown in Fig. 2.

III. Simulation Experiment

We conducted simulation and practical experiments on the above theory, focusing on the study of lateral and axial displacements of two optical multimode fibers. The choice of these fibers is reached after considering the structures of the two main types of single-mode and multimode fibers.

Multimode optical fibers have been chosen due to their many advantages in our application, such as larger fiber diameter, which favors easy coupling of optical fibers and operation in a wide frequency range, allowing the use of different types of optical sources and receivers.

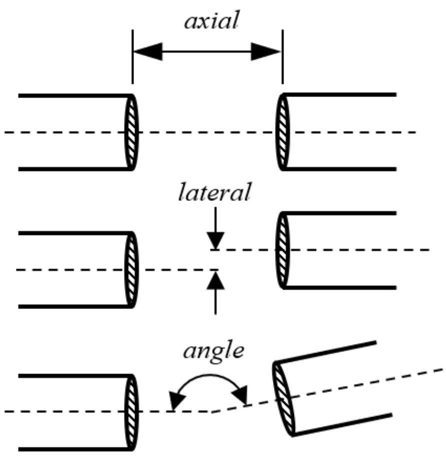
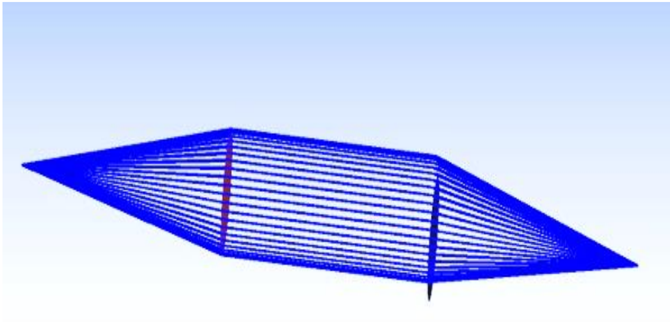
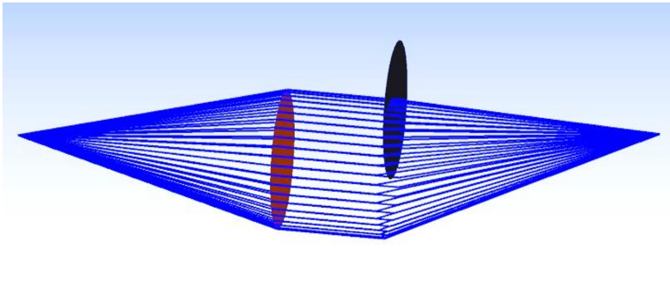


Fig. 2. Three types of displacement in optical fibers: axial, lateral and angular.

We initially conducted an experiment with Zemax software. [9]. The aim is a simulation study of the two types of displacements shown in Fig. 3.



a)



b)

Fig. 3. Visual presentation of experiments using Zemax software: a) axial displacement; b) lateral displacement.

In the case of axial displacement, we position the two fibers with a slight displacement in order to simulate a real situation in which it would be difficult to achieve perfect coordination of the positions of the two fibers, and then change the distance from 1 to 5 mm. The interesting thing about this experiment is that the efficiency changes nonlinearly, for example the data attached in Table 1.

TABLE I
RESULTS IN AN EXPERIMENT WITH AXIAL DISPLACEMENT IN THE RANGE OF 1 TO 5 MM IN 1 MM INCREMENTS.
THE UPPER ROW SHOWS THE OFFSET IN MM, AND THE LOWER ROW SHOWS THE EFFICIENCY IN %.

1 mm	2 mm	3 mm	4 mm	5 mm
44.89%	45.94%	44.96%	45.56%	45.41%

In the lateral offset, we initially positioned the two fibers perfectly, then we gradually offset one, the efficiency of the received signal is reduced in percent. Table 2 shows simulation data at 0 and 1.0 mm offsets.

TABLE II
RESULTS OF A LATERAL DISPLACEMENT EXPERIMENT IN THE RANGE 0 TO 1.0 MM IN 0.2 MM INCREMENTS.
THE UPPER ROW SHOWS THE OFFSET IN MM, AND THE LOWER ROW SHOWS THE EFFICIENCY IN %.

0 mm	0.2 mm	0.4 mm	0.6 mm	0.8 mm	1.0 mm
100%	89.42%	77.85%	66.38%	56.00%	44.85%

As can be seen from the data obtained in the case of lateral displacement, the efficiency decreases lazily. In addition, there is a much higher ratio in the differences from the initial and last moment of the displacement compared to the first simulation with axial displacement.

IV. PRACTICAL EXPERIMENT

After conducting theoretical calculations and a simulation experiment, we decided to conduct a real experiment using a source and receiver of optical radiation, multimode optical fibers and experimental stands with mounted calibrated micrometer screws in order to most accurately record the displacements. A photo from the experimental staging of the real experiment is presented in Fig. 4.

Through the above experimental setup we have conducted real experiments similar to the simulation ones, as in the axial displacement we have positioned the fibers at a distance of 0.1 mm from each other and we have displaced them up to 28.1 mm with a step of 2 mm. The obtained real results in dBm from the receiver of optical radiation are shown in Table 3.

Similarly to the experiment with axial displacement, we conducted one with lateral displacement, taking into account the diameter of the optical fiber. In this case the displacements are in steps of 10µm and we have performed 6 displacements, and after the third one we can see a large increase in the attenuation in dBm and respectively the excess of subsequent displacements. The obtained results are presented in Table 4.

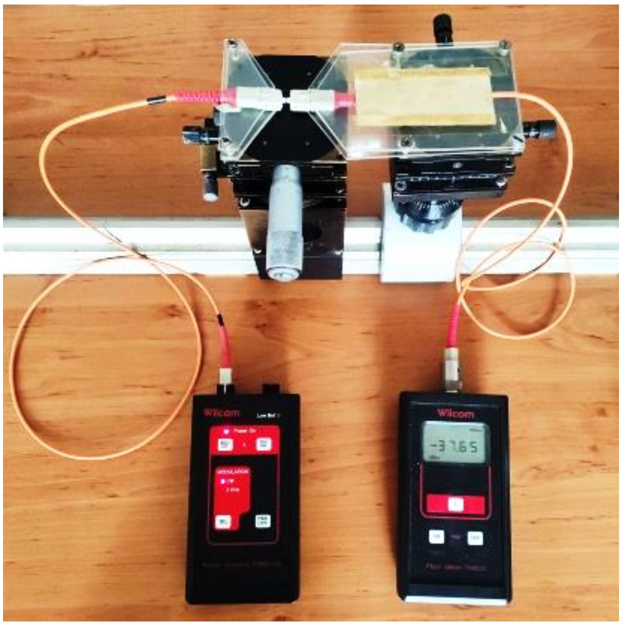


Fig. 4. Experimental setup for axial and lateral displacement of multimode optical fibers.

TABLE III
RESULTS IN DBM WITH AXIAL DISPLACEMENT OFFSET OF 0.2 MM IN THE RANGE OF 0.1 TO 30.1 MM.
THE UPPER ROW SHOWS THE DISPLACEMENT IN MM, AND THE LOWER ROW THE LEVEL IN DBM.

0.1 mm	2.1 mm	4.1 mm	6.1 mm	8.1 mm
-29.44	-30.72	-33.61	-36.22	-38.28

10.1mm	12.1mm	14.1mm	16.1mm	18.1mm
-39.89	-41.36	-42.53	-43.61	-44.53

20.1mm	22.1mm	24.1mm	26.1mm	28.1mm
-45.42	-46.16	-46.86	-47.48	-48.18

TABLE IV
RESULTS IN DBM WITH LATERAL DISPLACEMENT OFFSET OF 10 MICROMETERS IN THE RANGE OF 10 TO 60 MICROMETERS.
THE UPPER ROW SHOWS THE DISPLACEMENT IN MM, AND THE LOWER ROW THE LEVEL IN DBM.

10µm	20µm	30µm	40µm	50µm	60µm
-26.54	-28.35	-41.67	-51.46	-52.92	-54.64

V. CONCLUSION

From the conducted theoretical simulation and real experiments, we see that with side offset we have a big difference in efficiency, respectively attenuation in dBm, from which we can conclude that the method with side offset can be used when building a system with minimal deviations caused by signals with a small dynamic range, while in the case of axial displacement the changes are manifested in much larger displacements.

According to the conducted experiments, it could be said that through this optical method for collecting and studying the dynamic range of signals by displacing multimode optical fibers, different vibrations caused by sound waves in the whole audible frequency range can be reported. Accordingly, with the axial displacement method, due to the lower sensitivity and the need for greater physical displacement, it could be used in the study of high sound pressure, while the lateral displacement method can be used to detect sound waves with low sound pressure, due to the high sensitivity caused by the required minimum lateral displacement.

These methods could find applications in the design of optoacoustic measuring microphones in a wide range of applications, from measuring low-frequency vibrations in buildings to detecting high-frequency sounds with low sound pressure levels.

ACKNOWLEDGEMENT

We would like to thank the Research and Development Sector at the Technical University of Sofia for the financial support.

We would like to express our sincere gratitude to the Faculty of Telecommunications at the Technical University of Sofia for providing the laboratory base.

REFERENCES

[1] G. Agraval, *Fiber-Optic Communication Systems*, John Wiley & Sons, 2002.

[2] L.B. Stotts, *Free Space Optical Systems Engineering: Design and Analysis*, John Wiley & Sons, 2017.

[3] M. B. Marinov, B. T. Ganev and D. N. Nikolov, "Indoor Air Quality Assessment Using Low-cost Commercial Off-the-Shelf Sensors," 2021 6th International Symposium on Environment-Friendly Energies and Applications (EFEA), pp. 1-4, 2021.

[4] V. Alwayn, *Optical Network Design and Implementation*, Cisco Press, 2004.

[5] M. Bass, *Fiber Devices and Systems for Optical Communications FIBER OPTICS HANDBOOK*, McGRAW-HILL, 2002.

[6] Z. Ding, C. Wang, K. Liu, J. Jiang, D. Yang, G. Pan, Z. Pu, T. Liu, “Distributed Optical Fiber Sensors Based on Optical Frequency Domain Reflectometry: A review”, Sensors, vol. 18, no.4, pp.1072, 2018.

[7] W. Zhang, P. Lu, Z. Qu, J. Zhang, Q. Wu, D. Liu, “Large-Dynamic-Range and High-Stability Phase Demodulation Technology for Fiber-Optic Michelson Interferometric Sensors”, S0ensors, vol. 22, no.7, pp.2488, 2022.

[8] A.G. Alkholidi, K.S. Altowij, "Free Space Optical Communications-Theory and Practices", in Contemporary Issues in Wireless Communications, IntechOpen, 2014. Available: https://www.intechopen.com/chapters/47585

[9] P. Fu et al., "Coupling characteristic of tapered optical fiber based on ZEMAX", 2012 International Conference on Optoelectronics and Microelectronics, pp.73-76, 2012.