FORMATION OF AN INFORMATION LEAKAGE CHANNEL FROM AN OPTICAL FIBER BY THERMAL ACTION

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Abstract

The article evaluates the possibility of forming a channel for information leakage from a defect in optical fiber created by thermal action. The properties of optical fiber inhomogeneities caused by such action are currently practically unstudied, which determines the relevance of the research. The paper shows that local temperature action makes it possible to form a defect in optical fiber that allows part of the optical radiation to be removed beyond this fiber, that is, to create a channel for unauthorized data retrieval. It is shown that with an increase in the wavelength of optical radiation propagating along the fiber, the loss of radiation power on the defect formed by thermal action on the optical fiber increases. It is found that with the same loss of power on the defect formed by thermal action, the optical radiation power removed from such a defect has the greatest value when using G.652 optical fiber, and the least when using G.657 fiber. The results presented in the article can be used in designing systems for protecting information transmitted over fiber-optic communication lines.

Keywords: optical fiber; optical fiber defect; thermal effect; information leakage channel.

I. Introduction

Today, fiber-optic communication lines (FOCL) are widely used to transmit information. Optical fibers included in FOCL have advantages in speed and throughput compared to copper cores [1-3].

Data transmitted via optical fibers are more protected from unauthorized access to the transmitted information, but it is possible to form an information leakage channel by diverting part of the optical radiation from the fiber without breaking it [4]. Methods for implementing an information leakage channel include the formation of a macrobend and microbend of an optical fiber [5-6], as well as methods implemented on the basis of optical tunneling and compression of an optical fiber [7].

To connect devices implementing these methods, access to a section of optical fiber of a certain length is usually required, but it is not always possible to obtain it. At the same time, it is possible to create a connection zone for a device that provides unauthorized information retrieval by thermal action on the fiber. Such action leads to the appearance of non-uniformity of the optical fiber, from which part of the optical radiation power can escape beyond the fiber.

To detect thermally induced optical fiber inhomogeneities, it is necessary to know the characteristics of these inhomogeneities. The most important characteristics of inhomogeneities are the radiation power losses they introduce in the optical fiber and the proportion of optical radiation power diverted through the inhomogeneity formed outside the optical fiber. The first of these properties determines the possibility of detecting the presence of an inhomogeneity. The second allows us to estimate the possibility of using the inhomogeneity for data retrieval. However, the properties of thermally induced optical fiber inhomogeneities have not been studied to date. Therefore, the purpose of this work is to determine the characteristics of thermally induced optical fiber inhomogeneities.

II. Experimental setup and measurement technique

The objects of the study were standard single-mode optical fibers G.652, G.655 and G.657, which are quite often used in optical cables. The properties of optical fiber inhomogeneities caused by thermal effects were studied using an experimental setup, the structural diagram of which is shown in Fig. 1. The following designations are used in the diagram: RS – radiation source, OV – optical fiber, PM – power meter, D - diaphragm, FD – photodetector, G – burner, A – ammeter, V – voltmeter, PS – power supply, R_l – load resistor.

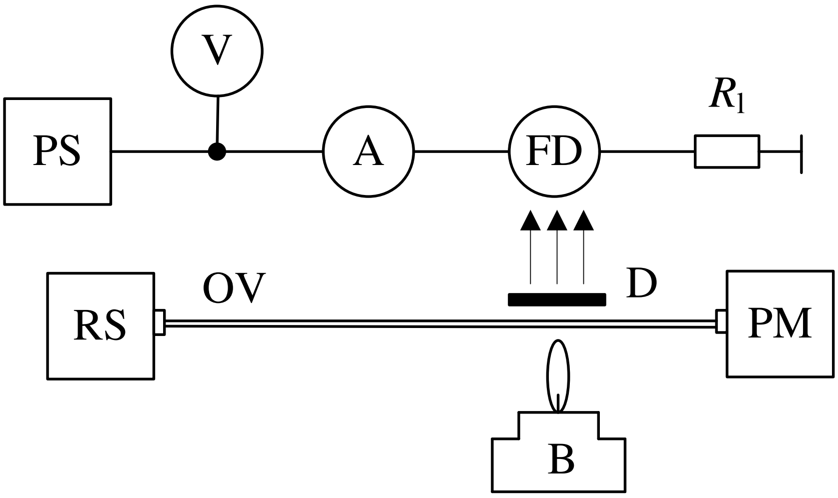

Figure 1: *Block Diagram of the Experimental Setup*

The principle of operation of the experimental setup: from the source RS, optical radiation enters the fiber OV, and from it – by measuring the intensity IM. From the constant voltage source PS, the supply voltage Us is supplied to the photodetector PD. The voltmeter V is needed to control the measurement of the reverse bias voltage. The ammeter A is used to measure the turn-off current flowing through the photodetector FD. A load resistor Rl with a nominal value of 1 kOhm is connected in series with the photodetector, which corresponds to the limitations of the current flowing through the photodetector.

The wavelength of the optical signal RS can change during the measurements and the values 1310, 1490, 1550 and 1650 nm are accepted, which corresponds to the "transparency windows" of single-mode optical fibers. During the studies, the optical signal power losses in the fiber were not taken into account, since its length was only 1 m. It should be noted that for all applications of optical fibers at constant lengths, a change in the wave intensity does not lead to an increase of 0.4 dB / km.

To form a defect in the optical fiber OV, a small part of this fiber was placed in the flame of the burner B. In this case, the diaphragm D was closed to limit the penetration of light and heat from the burner B onto the photodetector FD. During the studies, the photocurrent I_{ph} of the photodetector FD was calculated:

$$I_{ph} = I - I_d \tag{1}$$

where I_d is the dark electric current measured with the diaphragm D closed; I is the electric current measured with the diaphragm open.

The photocurrent value was used to determine the power of optical radiation arriving at the photodetector FD from the inhomogeneity of the optical fiber caused by the temperature effect: $P_b = I_{ph}/S$, where S is the sensitivity of the photodetector.

Note that different areas of the flame have different temperatures [8]. Thus, the temperature of the upper region of the flame is the highest (1500 K), and the temperature of the region located near the wick is the lowest (800 K) [9]. Therefore, the optical fiber was placed in the upper part of the flame. This allowed the fiber to be exposed to thermal action with a constant temperature of 1500K.

When performing measurements, the loss of radiation power D_l introduced by the defect caused by the temperature effect was determined by the following formula:

$$D_l = 10\lg\left(\frac{P}{P_{PM}}\right) \tag{2}$$

where P is the power of the radiation source RS, P_{PM} is the power of optical radiation arriving at the power meter PM.

The time of thermal action varied from 1 to 10 s. The longer the action on the optical fiber, the greater the insertion loss of radiation power on the created defect.

Note that with a thermal action time on the optical fiber of less than 1 s, it was not possible to form a defect with significant insertion loss of radiation power D_l. With a thermal action time on the optical fiber of more than 10 s, the insertion loss of radiation power Dl on the defect exceeded 20 dB. Such a value of D_l for zonal and trunk fiber-optic communication lines leads to the cessation of data transmission. Therefore, it was considered inappropriate to consider effects introducing such losses of radiation power.

The length of the section where the defect caused by the thermal effect occurred was about 1 cm. When the optical fiber was thermally affected, the fiber's paint coating, if any, burned in the area of this effect. After the thermal effect, the fiber became brittle in the area of the formed defect and broke even with a slight bend. In the absence of a paint coating, the appearance of the area where the thermal effect was carried out remained the same as before the effect.

To determine the radiation power D_b, diverted beyond the optical fiber from the inhomogeneity caused by the thermal effect, the following expression was used:

$$D_b = 10lg\left(\frac{Pb}{P}\right) \tag{3}$$

During the studies, the characteristics of the optical fiber inhomogeneities caused by thermal exposure were also estimated using the reflectometric method on an experimental setup, the structure of which is given in [10]. In this case, the inhomogeneity caused by thermal exposure was formed in the middle of an optical fiber 1.5 km long. During the measurements, reflectograms of signals in the fiber with such inhomogeneity were recorded, for which a reflectometer was connected to the input of the optical fiber. The duration of the reflectometer's optical pulse was 3 ns. With such a duration of optical pulses, the length of the dead zone for attenuation of the reflectometer used was minimal, which made it possible to determine with the greatest accuracy the locations of the thermal exposure and the amount of radiation power loss on the formed defect.

Measurements of the values of D_l and D_b, as well as reflectograms, were performed at room temperature T = 293 K.

III. Results of measurements and their discussion

During the research, a defect in the optical fiber was created by thermal action on the optical fiber with a burner flame (Figure 1). In this case, the magnitude of the power loss in the defect depended on the time of action on the optical fiber of the flame exposed to the flame.

During thermal action, diffusion of impurities introduced into the fiber during its production can occur in the optical fiber. Such diffusion leads to a change in the absolute values of the refractive indices of the core and cladding of the optical fiber at the point of thermal action, and, consequently, their difference. This leads to a violation of the condition for the existence of one mode in a single-mode fiber and the appearance of additional modes. Redistribution of energy between modes leads to a loss of power of the transmitted optical signal and the release of energy of additional modes beyond the fiber in the area of its local heating. Removal of the paint coating also contributes to the release of energy of optical radiation beyond the fiber.

The results of measuring the optical radiation power loss for the same defect caused by the thermal effect on the optical fiber for different wavelengths of optical radiation are presented in Table 1. As follows from the obtained results, the longer the wavelength, the greater the optical radiation power loss for all the studied optical fibers. Table 1 also displays information on the optical radiation power removal from the side surface of the optical fiber in the defect area. As can be seen from the obtained data, with increasing wavelength, more optical radiation power is removed from the side surface of the optical fiber in the defect area. The above trends are observed for all the studied optical fibers. Note that the defects of G.652 optical fibers, which have a lower optical radiation power loss than the other studied optical fibers, had higher values of the optical radiation power removed from the side surface of the optical fiber in the defect area. This is due to the different internal structure of the studied fibers.

Table 1: *The results of measurements of the power loss of optical radiation in the area of the defect caused by thermal effects on the optical fiber*

Type of optical fiber	λ, [nm]	Optical radiation power loss, [dB]	Optical power diversion, [dB]
G.652	1310	0,40	-48,70
	1490	1,23	-48,10
	1550	1,29	-47,40
	1625	1,51	-46,90
G.655	1310	0,97	-56,60
	1490	2,16	-56,10
	1550	2,79	-55,60
	1625	3,52	-55,10
G.657	1310	5,01	-57,80
	1490	5,27	-57,20
	1550	5,49	-56,30
	1625	6,10	-54,30

An analysis of the reflectogram section of the G.652 optical fiber containing a defect shows that the location of such a defect is characterized by the presence of a power drop in the form of a "step"

(Figure 2). The magnitude of such a power drop increases with increasing wavelength, i.e. for these defects, a dependence of the loss of optical radiation power on the wavelength of optical radiation is observed. Note that the reflectograms for these defects and their behavior with increasing wavelength of optical radiation are similar to the reflectograms characteristic of macrobends in optical fiber [11].

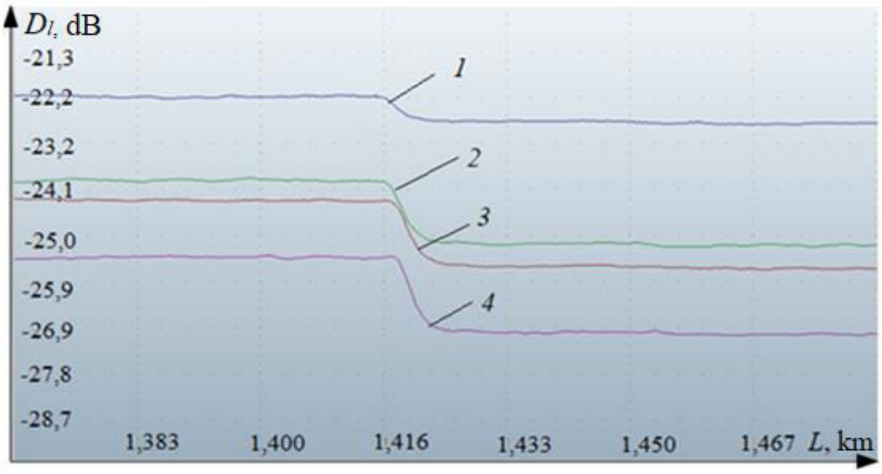

Figure 2: *The section of the reflectogram of the optical fiber G652 containing the defect, for wavelengths: 1 – 1310 nm, 2 – 1490 nm, 3 – 1550 nm, 4 – 1625 nm*

Reflectograms are given for the optical fiber G.652. Reflectograms for other optical fibers are identical. It can be seen from the reflectograms that an increase in the loss of optical radiation power on a defect leads to an increase in the value of the optical radiation power diverted from the defect. With the same value of the power loss on a defect, different values of the optical radiation power diverted from the defect were observed for different wavelengths of optical radiation.

Figure 3 shows typical dependences of the value of the radiation power Pref diverted from a defect formed as a result of thermal exposure on the value of the loss of radiation power that occurred due to this defect for different wavelengths. As follows from the obtained dependences, with an increase in the loss of radiation power, the value of the radiation power diverted from the defect Pref increases. The obtained dependences were nonlinear. This indicates that the power losses on such a defect are caused not only by the radiation that goes beyond the optical fiber in the area of this defect.

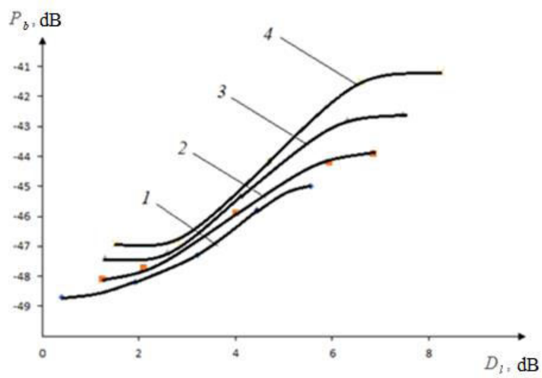

Figure 3: *The dependence of the removal of optical radiation power from a defect formed as a result of thermal exposure on the magnitude of the power loss caused by this effect for wavelengths: 1 – 1310 nm, 2 – 1490 nm, 3 – 1550 nm, 4 – 1625 nm*

In the course of the conducted study, a comparison of the optical radiation power removal from the defect was performed for different optical fibers. During the comparison, defects were created in each of the studied optical fibers that introduced the same power loss at the same optical radiation wavelength. The optical radiation power loss was measured for the same optical radiation wavelength. Information on the obtained results is presented in Table 2. Based on the data presented in Table 2, the highest power removal from the defect formed as a result of thermal exposure is observed for the G.652 optical fiber, and the lowest – for G.657. This is observed for all studied radiation wavelengths. Such a difference in the values of power removal from the defect is associated with a different internal structure of the studied optical fibers. Note that the studied fibers have a difference in the geometric dimensions of the core and cladding of the fiber [12-14].

Table 2: *The results of measurements of the removal of optical radiation power from the lateral surface of the optical fiber in the area of the defect formed by thermal action*

Type of optical fiber	Wavelength, [nm]	Loss of power, [dB]	Power diversion from the side surface of the fiber in the defect area, [dB]
G.652	1310	3,5	-47,1
G.655			-52,8
G.657			-58,6
G.652	1490	4,5	-46,0
G.655			-52,0
G.657			-58,0
G.652	1550	5,0	-44,1
G.655			-51,0
G.657			-56,5
G.652	1625	6,0	-42,0
G.655			-50,7
G.657			-54,4

IV. Conclusion

It has been shown that by means of local temperature action it is possible to form a defect in an optical fiber, allowing part of the optical radiation to be removed beyond the fiber.

It has been determined that with an increase in wavelength, the power of optical radiation removed from a defect formed by thermal action on an optical fiber increases.

The studies have shown that with the same power loss on a defect formed by thermal action on an optical fiber, the removal of optical radiation power from such a defect has the greatest value when using G.652 optical fiber, and the least when using G.657.

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