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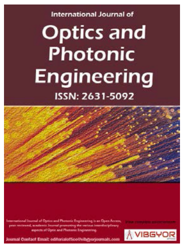

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Experimental Measurements of Attenuation and Recovery within Single Mode Optical Fiber Cables under the Effects of Gamma Radiation

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Abstract

Efficient transmission of data within optical fiber cables within radiation environments is a challenge. It leads to severe attenuations in the optical fiber cables. This issue is addressed in this manuscript. Experimental measurements are conducted in order to overcome the radiation influence on single mode optical fiber cables. Two experiments are implemented. The first one depends on 5 m single mode patch cords fiber cable. This cable is subjected to gamma radiation at different radiation doses of 5 kGy, 10 kGy, 15 kGy and 20 kGy with dose rate of 1.296 KGy/hr. These doses are the maximum doses that the cable of fiber is exposed in normal conditions in our radiation environment. The second experiment uses 3 m single mode fiber cable with different jackets. In this experiment, the cable is degraded by gamma radiation of doses 5 kGy, 10 kGy, 15 kGy and 25 kGy and dose rate of 2.273 KGy/hr. The fiber cables are degraded through gamma 1 radiation facility within Egypt Mega gamma1 in National Center for Radiation Research and Technology of Egyptian Atomic Energy Authority (EAEA). Then, the attenuation of these cables is measured in two different places in National Institute for Laser Science in Cairo University and Africa Teleco private company. The measurements are done using laser sources at spectral wavelengths of 1310 nm and 1550 nm. Hence, various readings of attenuations in dB are demonstrated. Attenuation recovery is of primary concern. It is executed within 36 days. The experimental results confirm the superiority of operation at 1550 nm over that of 1310 nm. The experimental measurements are performed before and after radiation degradation for comparison purposes. The recovered attenuation achieves better results comparable to results before degradations.

Keywords

Fiber cable, Single mode, Attenuation, Power meter, Light source, Gamma radiation and optical recovery

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Introduction

Optical fiber plays an important role in communication world because its low weight, high immunity to electromagnetic interference [1]. Optical fibers have many advantages over metallic lines: Low Attenuation, Very High Bandwidth (THz), Small Size, low weight, and Low Security Risk [2]. Since optical fibers were applied in nuclear radiation environments like space systems, nuclear power plants and military facilities as signal transmission media, people began to study effects of radiation on optical fibers to measure the changes of optical fiber parameters [3-5]. Research results are used to evaluate the variation degree of optical fiber system performance and their working lives under nuclear circumstance, and to search methods for reducing radiation-induced loss. When radiation projects to optical fibers, some effects will produce: increase of optical fibers absorption loss, changes of optical fiber refractive index and development of optical fiber luminescence. Radiation induced attenuation in optical fiber [6,7]. These excess optical losses are due to the generation of point defects in the pure or doped silica glass constituting the light propagating medium [8-10]. Radiation damage of material due to incident photon flux is varied, depending upon the material through which the photon propagate and the photon energy of the radiation [11]. Nowadays optical fiber is used in nuclear radiation environments, so it is necessary to study the radiation effects on it. The effects of γ-ray radiation on optical fiber are studied [12,13]. Damage ranges from simple heating, as photons are absorbed, to ionization and even photon-nuclear disintegration if the interacting photon energy is of the order of 10 MeV or greater. According to different photon energy, effects of γ-ray on materials include: Photoelectric, Compton, electron pair and scattering effects [14]. The purpose of this research is to provide experimental data for reducing radiation-induced loss of optical fibers and to attempt to evaluate system performance degradation of optical fibers under nuclear environments [15]. In this study, two experiments are studied to show the effects of gamma ray-radiation on single mode optical fiber cables, different doses of gamma radiation are applied at different wavelengths and the attenuation is measured [16,17]. Radiation induced attenuation is varied in accordance with fiber wavelength, its composition and the applied doses. Finally, the recovery of optical parameters after time was noticed. This paper is organized as follows; Section (2) includes the experimental procedure and system configuration. The attenuation measurements within optical fiber cables are declared in Section (3). The experimental results and discussions are illustrated in Section (4). Finally, Section (5) is devoted for work conclusion.

Experiment Procedure and System Configuration

In this experimental work, eight samples of single mode optical fiber were used. Four samples of them are 5 Meters patch cords. These patch cords are Amphenol and duplex patch cords with diameter 3.0 mm. Besides, these patch cords have coating of optical fiber non-conductive riser (OFNR). The connectors are FC/PC connectors that environmentally stable and reliable. The other four samples are 3 meters NGFAT SM 36c HN-04 0346 Telecom Egypt 1/2014/421 vr. 2015. These samples are shown in Figure 1.

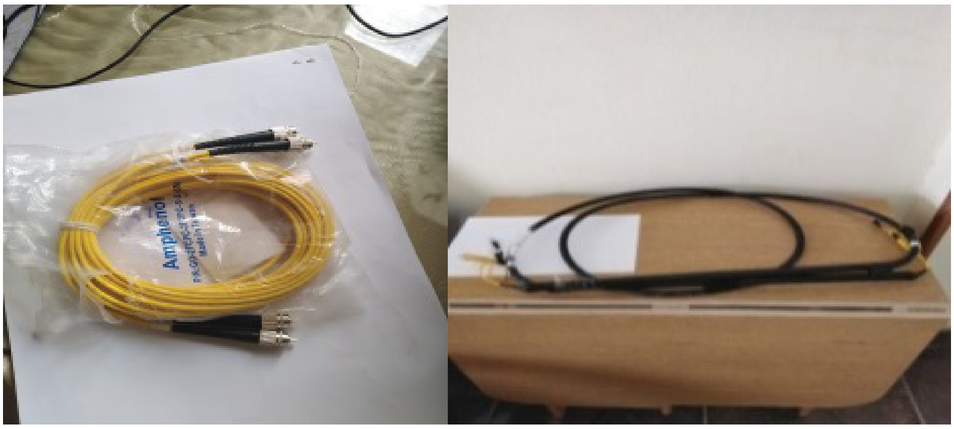

Figure 1: Five meters (5 m) patch cord fiber cable & three meters (3 m) telecom Egypt fiber cable.

Figure 2: Laser source & power meter of Africa Teleco Company and Laser Science Institute.

Figure 3: Attenuation measurement within optical fiber cables by power meter.

The irradiation has been done by cobalt-60 (^{60}Co) source at gamma 1 radiation facility within Egypt Mega gamma1 in National Center for Radiation Research and Technology of Egyptian Atomic Energy Authority (EAEA). The power of the source is 1.1 MeV. The first four samples were put at the same time in radiation field but taken out at different times. The used doses are (5 kGy, 10 kGy, 15 kGy, 20 kGy) at dose rate 1 kGy/46.5 minute. Indian Gamma Cell (Ge 4000 A) is used for the irradiation process and the other four samples were put separately at Egypt Mega Gamma1 at doses (5 kGy, 10 kGy, 15 kGy, 25 kGy) with dose rate 1 kGy/26.4 minute. Measurements of attenuated radiation within these cables are done after 48Hours from exposing it to radiation. On other words, these irradiated cables are left 2 days for transporting them to the measurement places. Then, the attenuation is measured.

The experimental measurements for fiber attenuation are done at two different places: engineering applications in national institute for laser science in Cairo University and Africa Teleco Company. The used instruments are power meter and laser source. The utilized practical wavelengths are of 1310, 1550 nm. These instruments are illustrated in Figure 2.

Attenuation Measurements within Optical Fiber Cables

The block diagram of the system by which the power losses of fiber samples were measured is shown in Figure 3. One end of the fiber was connected to the light source and the other end to the power meter. The light source sends a wavelength of light down the fiber. However, the power meter at the other end of the cable reads that light. This meter determines the amount of signal loss. This loss is computed by

Power loss = Reference Power (Source) - Tested Power (Received)

For first four samples, the dose rate was 1 kGy/26.4 minute to get total dose of 25 kGy. However, the total radiation time was 11 Hours. For other four samples, the irradiated dose rate was 1 kGy/46.5 minute within total dose of 20 kGy and total radiation time 15.5 Hours. The high doses on optical fiber lead to dark and black of FC connector as shown in Figure 4. These variations indicate the radiation induced attenuation that varied according to wavelength, dose and fiber composition. It is found that 1550 nm wavelength was more stable than 1310 nm wavelength. Also, the attenuation is increased with radiation dose. However, the fiber becomes unstable at high doses. Thus, it leads to unstable measure of fiber attenuation.

Additionally, the power losses of fiber cable samples were measured before gamma-radiation using the same experimental components (power meter and light source) at wavelengths of 1550 nm and 1310 nm as depicted in Figure 5. The output power losses were measured after irradiation after specific time. The power loss is calculated with

(a) Patch cord cable (b) Instruments in Africa Teleco Company

Figure 4: The influence of ionizing radiation to FC connectors.

(a) Instruments of Laser Science Institute (b) Instruments in Africa Teleco Company

Figure 5: Measurements of power losses.

respect to reference power with different doses. These values of power losses are shown in the next subsection. It is concluded that losses are varied according to applied doses depending on applied wavelength and fiber composition.

Experimental Results and Discussion

Different lengths of optical fiber cables are utilized. These are with 5 m single mode patch cords fiber cable and 3 m single mode fiber cable. Also, these optical fiber cables with different jackets. Optical fiber cables with double pairs are irradiated. The fiber cables are irradiated within Egypt Mega gamma1 of radiation technology center at Egyptian Atomic Energy Authority (EAEA). The cables are subjected to gamma ionized radiation at different radiation doses of (5, 10, 15, 20 and 25) kGy. The exposure time limits to ionizing radiation are between 3.30 Hours to 15.25 Hours. Moreover, the attenuation within cables due to gamma ionizing radiation is measured at two different economical places. These measurements are carried out at national institute of Laser science (NILS) in Cairo University, and Africa Teleco Company. The measurements at NILS are performed at 1550 nm wavelength of transmitted optical signal within cable.

Table 1: Power losses for different optical fiber (Telecom Egypt 3 m length) pairs (1 and 2) using reference power of 1 mw (0 dB).

Power loss (mw) & (dB) at λ = 1550 nm								
Related samples with Dose (kGy)	Pair 1				Pair 2			
	Before Irradiation		After Irradiation		Before Irradiation		After Irradiation	
	(mw)	(dB)	(mw)	(dB)	(mw)	(dB)	(mw)	(dB)
Sample (1) 5	0.3855	4.1398	0.5909	2.285	0.9966	0.0148	0.5914	2.281
Sample (2) 10	0.9979	0.0091	0.6779	1.688	0.5239	2.8075	0.4847	3.145
Sample (3) 15	0.9722	0.1224	0.5435	2.648	0.9997	0.0013	0.6161	2.104
Sample (4) 25	0.9989	0.00478	0.9849	0.0661	0.9786	0.0939	0.5365	2.704

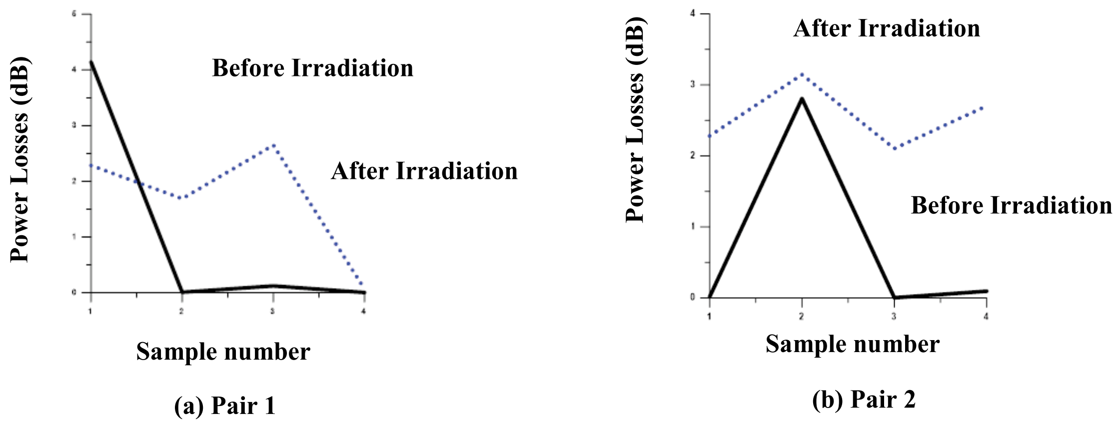

Figure 6: The variation of power losses under influence of gamma doses with operating wavelength of 1550 nm, reference power of 1 mw (0 dB) and cable length of 3 m measured at NILS.

The measured power loss in mw for pair 1 and pair 2 of optical fiber cable with length 3 m at NILS using reference power of 1 mw is depicted in Table 1, but it converted to dB in the related figures. The measurements are done before and after exposure to gamma radiation. It is expected that larger attenuation is observable after irradiation for both fiber cable pairs (1 and 2). However, a variation in the experimental results is achieved. For irradiation at 5 kGy, the loss after exposure is lower than before exposure for pair 1. However, at (10, 15, 25) kGy, the measured attenuation after exposure is higher than before exposure. This unexpected situation may be due to recovery process that happened for the fiber cable. Since, attenuation measurements are done after 48 Hours of exposure. Besides, this undesirable influence may be resulted from stochastic exposure of cable to radiation. The radiation may be concentrated to specific segment of cable. Additionally, the power losses after irradiation of pair 2 are noticed to be higher than losses before irradiation at all doses, Figure 6 shows the schematics related to these results. The connector color is observed to be changed from its normal color to be darkness as depicted in Figure 4.

Table 2 and Table 3 show the measured power losses for the same samples but they measured in Africa Teleco Company at reference power (0 dB) and at two wavelengths 1310 nm and 1550 nm ,it is noticed from Table 2 at wavelength 1550 nm for pair 1 at doses (5,10 and 25) kGy, the measured power losses (in dB) after irradiation are increased than before the exposure to gamma radiation but at 15 kGy dose, the power losses after irradiation is decreased than before irradiation, for pair 2 it was noticed that power losses are decreased after irradiation than before irradiation for all dosses except at 25 kGy the attenuation was increased after irradiation. Table 3 shows the measured losses at 1310 nm wavelength pair 1 and pair 2 (the losses measured in dB) from the table at doses (5, 10, 25 kGy) the attenuation is increased after irradiation than before it, but for 15 kGy dose the losses decreased after irradiation than before

Table 2: Power losses for different optical fiber (Teleco Egypt cable 3 m length) pairs (1 and 2) using reference power of 0 dB.

Power loss (dB) at λ = 1550 nm				
Related samples with Dose (kGy)	Pair 1		Pair 2	
	Before Irradiation	After irradiation	Before Irradiation	After Irradiation
Sample (1) 5	-0.51	3.5	0.92	0.87
Sample (2) 10	0.15	0.89	1.19	0.64
Sample (3) 15	2.85	0.24	3.42	0.12
Sample (4) 25	0.07	1.29	0.10	1.25

Table 3: Power losses for different optical fiber (Teleco Egypt cable 3 m length) pairs (1 and 2) using reference power of 0 dB.

Power loss (dB) at λ = 1310 nm				
Related samples with Dose (kGy)	Pair 1		Pair 2	
	Before Irradiation	After Irradiation	Before irradiation	After irradiation
Sample (1) 5	-0.17	4.10	0.07	-2.02
Sample (2) 10	-2.79	-2.14	-1.62	0.04
Sample (3) 15	-0.06	-2.75	0.74	-3.16
Sample (4) 25	-3.10	-1.83	-2.87	-1.94

Table 4: Power losses for different optical fiber (patch cord cable 5 m length) pairs (1 and 2) using reference power of 0 dB.

Power Loss (dB) at λ = 1550 nm				
Related samples with Dose (kGy)	Pair 2		Pair1	
	Before irradiation	After irradiation	Before irradiation	After irradiation
Sample (1) 5	1.06	1.02	0.75	1.9
Sample (2) 10	0.81	0.96	0.29	1.27
Sample (3) 15	0.41	0.13	1.05	0.64
Sample (4) 20	0.85	0.38	0.64	0.46

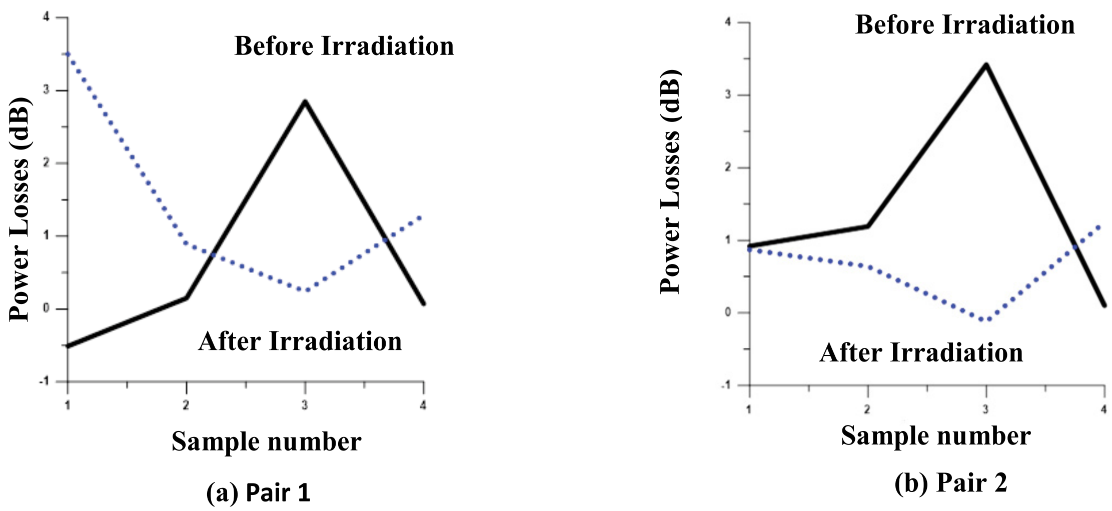

Figure 7: The variation of power losses under influence of gamma doses with operating wavelength of 1550 nm, reference power of 0 dB and cable length of 3 m measured at Africa Teleco Company.

it, this is for pair 1 of sample, for pair 2 it was noticed that at 5 kGy, 15 kGy the measurements of losses after irradiation are decreased than before irradiation but at doses (10, 25) kGy the losses increased after irradiation than before it. From this results the variation of losses by increasing or decreasing may be due to the composition of fiber cable, (in this work the used cables are single mode within pure silica core) itself and radiation may be concentrated to specific segment of cable; these

Table 5: Power losses for different optical fiber (patch cord cable 5 m length) pairs (1 and 2) using reference power of 0 dB.

Power loss (dB) with at λ = 1310 nm				
Related samples with Dose (kGy)	**Pair 1**		**Pair 2**	
	before irradiation	**after irradiation**	**before irradiation**	**after irradiation**
Sample (1) 5	1.38	-1.81	1.85	-1.81
Sample (2) 10	0.59	-1.8	1.07	-2.35
Sample (3) 15	1.57	-2.51	0.85	-2.91
Sample (4) 20	1.23	-2.75	1.09	-2.61

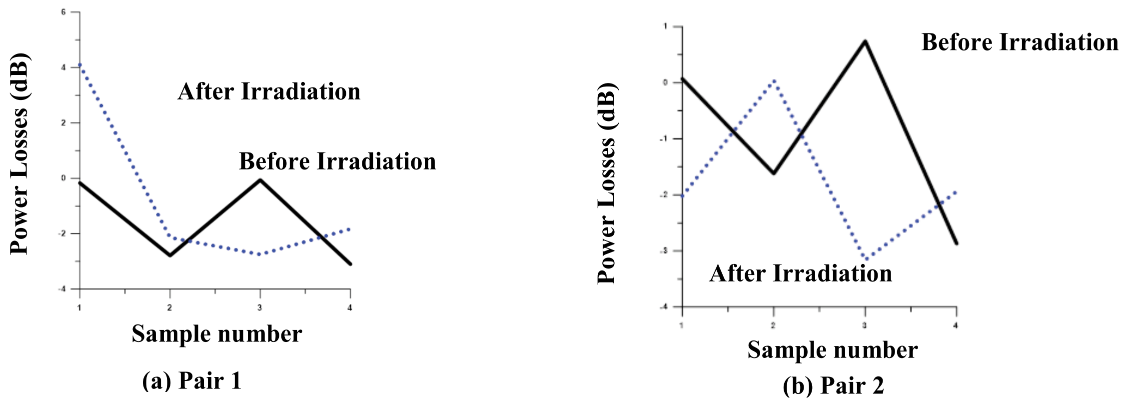

Figure 8: The variation of power losses under influence of gamma doses with operating wavelength of 1310 nm, reference power of 0 dB and cable length of 3 m measured at Africa Teleco Company.

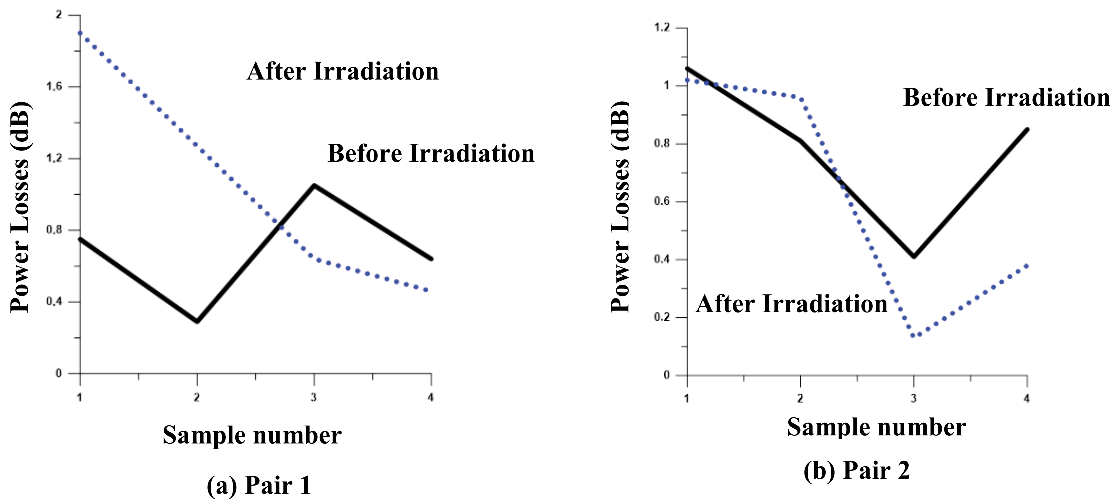

Figure 9: The variation of power losses under influence of gamma doses with operating wavelength of 1550 nm, reference power of 0 dB and cable length of 5 m measured at Africa Teleco Company.

results are shown in Figure 7 and Figure 8.

The measured power losses of the other type of cable sample which is 5m patch cord with coating of optical fiber nonconductive riser (OFNR) two pairs are shown in Table 4 and Table 5, respectively. These measurements are done in Africa Teleco Company at different wavelengths and different doses. From Table 4 it is noticed that the applied doses of gamma radiation are (5, 10, 15, 20) kGy with dose rate of 1 kGy/46.5 minute. the measured attenuation (in dB) is at wavelength 1550 nm with reference power 0dB, for pair1 the power losses are increased after the exposure to radiation dose than before the irradiation this is at (5, 10) kGy dose, but at doses (15, 20) kGy the measured power losses are decreased after irradiation than before it. For pair 2 it is noticed from the table that the power losses is decreased after irradiation than before it for all doses except at dose 10 kGy the attenuation is increased after irradiation. Table 5 shows the results for the same sample at the same reference power at the same place but at wavelength 1310 nm from the measured results, it is seen for pair 1 and pair 2 the power losses are decreased for all doses after the exposure to gamma radiation this is unexpected results, but it is noticed that, the measurements for this wavelength were not stable. Figure 9 and Figure 10 show the schematics for these results.

Attenuation recovery results within optical fiber

The unexpected results seen above are due to some reasons, the recovery process which begins after irradiation by some hours is one of them, to confirm that these measurements are done again After 36 days, we had measured the 5meter patch cord samples by the same method, the recovery was noticed. The power losses are measured in laser science institute in Cairo university at 1550 nm

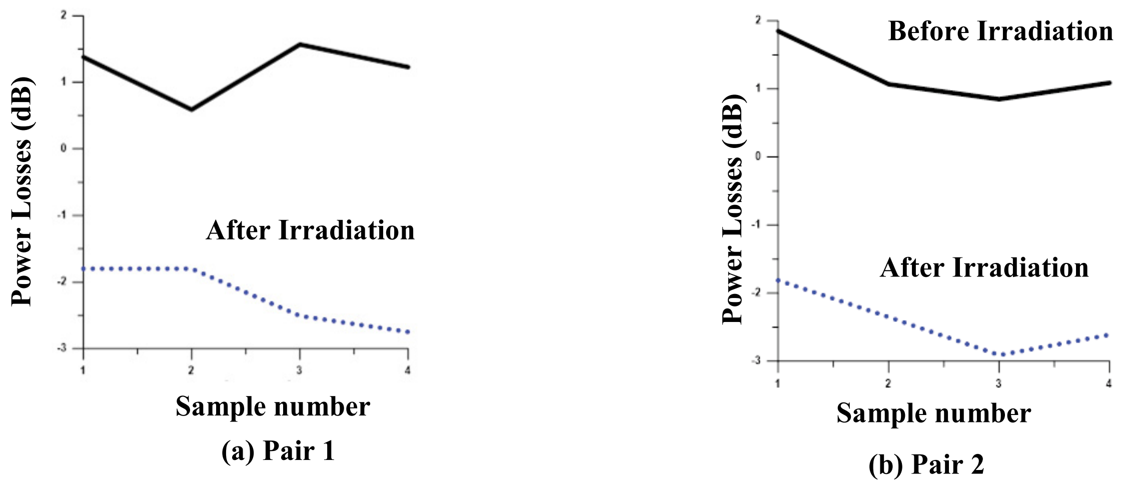

Figure 10: The variation of power losses under influence of gamma doses with operating wavelength of 1310 nm, reference power of 0 dB and cable length of 5 m measured at Africa Teleco Company.

Table 6: Power losses for different optical fiber (patch cord 5 m length) pairs (1 and 2) using reference power of 2.09 mW (3.2015 dB) at 11/4/2019 & 7/3/2019.

Power loss (mw) at λ = 1550 nm								
Related samples with Dose (kGy)	**Pair 1**				**Pair 2**			
	Date 7 /3/2019		**Date 11/4/2019**		**Date 7 /3/2019**		**Date 11/4/2019**	
	mW	dB	mW	dB	mW	dB	mW	dB
Sample (1) 5	2.089	3.1994	0.889	0.5109	2.0827	3.1863	0.84	0.7572
Sample (2) 10	2.089	3.1994	1.03	0.1284	2.0844	3.1898	0.681	1.6685
Sample (3) 15	2.0604	3.1395	0.92	0.362	2.0629	3.1448	1.061	0.2572
Sample (4) 20	2.0884	3.1981	0.835	0.783	2.0872	3.1956	0.62	2.0761

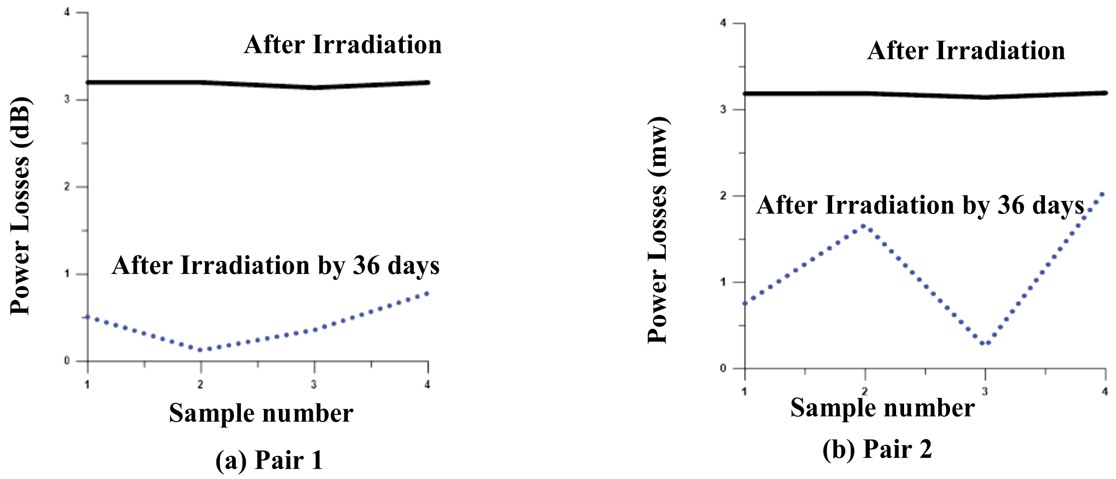

Figure 11: The variation of power losses under influence of gamma doses with operating wavelength of 1550 nm, reference power of 2.09 mw and cable length of 5 m after 36 days after irradiation measured at NILS.

wavelength (in mw) reference power of 2.09 mw, it converted to dB in related figures. Table 6 shows the measured losses after this period of time, for pair 1 and pair 2 a great recovery is noticed from great decreasing of measured losses after 36 days for all doses. Figure 11 shows the related schematic for these results. from the figures it is noticed that the attenuation was improved any way but it is noticed, for pair 1 at dose (10) kGy the decreasing in power losses is greater than the remained doses (5, 20) kGy. For pair 2 at doses (10, 20) kGy the decreasing in power losses is greater than the remained doses.

Conclusion

The exposure of optical fiber cables to gamma radiation leads to various degradations. One of these degradations is the darkness color of the cable connector. Additionally, the radiation leads to attenuation within optical fiber. Experimental measurements for this attenuation are of primary concern. So, two different cable lengths are utilized for experiments. One of these cables is of length 3 m and the other has length of 5 m. Both cables with different jackets are exposed to different radiation doses at Egypt Mega gamma1 in RTC of EAEA. The measured attenuation is carried out at NILS and Africa Teleco Company using laser source supported with power meter. The measurements are done at operational wavelength of 1550 nm and 1310 nm that proved to be satisfactory for wave transmission within optical fiber cables. The experimental results confirm that random attenuation inside optical fiber cables is resulted that in turn degrades the performance of transmitted wave. In addition, the unexpected attenuation results are variants. It may be due to recovery process that happens immediately after specific time period. Also, the lattice damage of exposed optical fiber in certain part is higher than other segments of the cable. On other words, the damage is concentrated in specific segments of the cable. It is observed that attenuated fiber cables are influenced by fiber structure, fiber core, fiber cladding, material composition, wavelength, total dose and dose rate. Composition of optical fibers (in this work, it is single mode fiber within pure silica core) is directly related to the radiation induced attenuation. The attenuation recovery process inside optical fibers is accomplished. It is based on reconstructing bonds that damaged during irradiation. As a last conclusion, the attenuation issue in optical fiber can be handled. Also, the experimental measurements of fiber attenuation confirm the possibility data transmission under radiation environments due to attenuation recovery of fibers.

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