Optica Applicata, Vol. LII, No. 4, 2022
DOI: 10.37190/oa220407

Utilization of telecommunication optical routes to power fiber-optic polarization sensors

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A single-mode telecommunication optical route can be used for reliable power supplies of a remote non-electric temperature fiber-optic polarization sensor, but the optical route, due to many physical factors, affects an immediate state of polarization during the transmission. This negative phenomenon changes the sensitivity of the sensor itself. The thesis proposes two main approaches to solving that problem. The first approach is based on the suitable connection of a depolarizer and linear polarizers. The second approach is based on signal interference, which takes place in a polarization -maintaining fiber coupler. This article also evaluates the advantages and disadvantages of the two approaches and graphically demonstrates the functionality of the fiber-optic sensor, which was tested by applying a container with water of different temperatures. A big advantage of this type of sensor is that it is not necessary to have components, that are dependent on electricity, near the monitored place, where there may be no access to electricity, or the place may be sensitive to an electric charge. Paper demonstrates the possibility of successfully powering the non-electric sensor via a classical optical route.

Keywords: power supply, optical route, polarization, temperature sensor.

1. Introduction

Utilization of optical fibers is nowadays widely used in many different fields around the world. One of the main areas of usage is in data transmission. For example, single -mode fibers are utilized in wide area networks and backbone routes. The main advantages are security, reliability, volume of transmitted data, and cost, despite initial expenses. Optical communication is not restricted to only fibers, but also takes place in free space [1–3]. This type of communication brings new challenges. Weather and other conditions may negatively affect the beam, [4–6] but the beam inside the optical fiber is exposed to many similar influences, such as thrust, temperature changes, humidity, velocity changes, amongst others. The use of optical fibers in sensor technology is very common, not only as signal transmitters, but also as the sensors themselves, and the above-described negative influences can be turned into intended properties for measuring external influences. Different approaches [7–10] are suitable for different purposes, but the fiber optic polarization sensor has a lot of advantages. Real-time long -distance monitoring, immunity to electromagnetic radiation, and simple construction are important examples. Fiber-optic polarization sensors play a very important role for monitoring purposes [2] and reacting to temperature changes and thrust as well.

The goal of this work was to construct a temperature sensor for the protection of objects in dangerous environments with the possibility of an explosion. This is a main advantage of fiber-optic sensors due to their non-electricity character. Another possible usage can be found in the petrochemical industry due to the sensor's inertness, in aviation because of its small weight and in many other branches. The sensor must be sensitive enough to react to small, fast temperature changes, must have immunity to electromagnetic radiation, and must not affect its surroundings. The fiber-optic sensor is the best solution described in [11–13], but powering it is not a simple task. The sensor needs to be powered by a quality optical source via a single mode telecommunication optical route. The problem is that the single-mode route naturally affects the polarization state of light, and in combination with a high degree of polarization causes the whole route to become the sensor [13]. Optical routes situated in a stable environment are less sensitive to changes, but a single mode fiber does not maintain polarization. It can cause a change of polarization, which affects the sensor, and thus it would not work properly, because the sensor would not be sensitive enough. For example, if the sensor's input comes from a linear +45° polarization, that, after passing through a rotated FC connector, turns into linear horizontal polarization, there would not be enough energy in all axes and so the response of the sensor will not be sufficient.

There are two main approaches to solving the problem in the thesis. The first approach is based on a depolarizator, which decreases the degree of polarization. Due to the depolarizator, the route does not behave like a sensor [14, 15]. The connected linear polarizer ensures quality power by allowing only the slow axis to pass. Light passes through a rotated FC connector, which equally spreads energy into both planes, y and x. The second linear polarizer is connected after the sensor releases only the slow axis, so that changes in polarization state are visible in the optical power as well. With a connected polarimeter, the second linear polarizer is not necessary.

The second approach is based on light interference between two sensors inside a fiber coupler. This is a fiber-based version of the Michelson and Mach–Zehnder interferometers. The circuit consists of a source, an optical route, a polarization maintaining fiber coupler, two sensors, and a polarization combiner. The polarization maintaining power coupler splits incoming optical power into two branches, where the sensors are situated. The first branch is a reference branch, where the sensor is isolated from external influences. The measuring sensor is connected to the second branch. The signal is then combined in the polarization combiner. Significant interference is then visible at the output.

For future research, it is possible to connect dense wavelength-division multiplexers to increase the capacity of fibers and maintain existing optical routes [15], so another wavelength can be added and dedicated for measuring purposes. Many basic principles and theories can be found [16] and they help us to understand not only mathematically, but also practically what takes place inside the fiber. References [11–13] are much more related to the sensor itself, but this article focuses on the overall connection of the single -mode route and other components to ensure quality power to the sensor.

This article also evaluates the advantages and disadvantages of individual connections and uses graphs to prove the functionality of the fiber-optic sensor. Not only must real measurements take place, but there is also room for simulations, as shown in [17]. Depending on the desired output, a polarimeter or a laser power meter were used for the measurements, but there is room for other types of data processing [17, 18]. These connections should help ensure object security, and the sensor can be, for example, placed in a dangerous environment that is sensitive to electric discharge.

2. Research methods

In this paper, there are two main approaches: the first approach is based on the connection of a depolarizer and the second is based on light interference. In both approaches, the sensor was tested for proper functionality by applying a container with water of different temperatures (0 °C, 48 °C). The reaction of the sensor to lower temperatures was tested by applying a container with water and ice (0 °C). In order to keep the same difference between temperatures with respect to the ambient temperature (24 °C), the sensor was tested at (48 °C), which tested its reaction to higher temperatures. After that, the results were evaluated, and the entire system was found to work properly [11]. Papers [19, 20] use similar methods, but the sensor is exposed to bigger temperature differences. The sensor in these connections also works and sufficiently reacts to the bigger temperature changes. This type of sensor is based on polarization state changes, but for initial cost savings measurements, the output optical power can be measured instead of the polarization state change. For that purpose, it was necessary to connect other components such as linear polarizers and polarization-maintaining power couplers, depending on the approach. The reactions and physical details of the sensor are more fully described in [12, 13]. The entire system operates at a wavelength of approximately 1550 nm. The measurements are initially taken by a polarimeter to ensure system functionality, but in subsequent measurements a laser power meter is used as a receiver. Another possibility for processing is described in paper [18].

2.1. Use of a depolarizer

The task of the depolarizer is to reduce the degree of polarization so that the light is spread evenly into all possible polarization states. That altered light has the degree of polarization around the depolarizer producer's declared value of 5%. This ensures that the energy is spread over multiple states, and the benefit is that it minimizes the negative impact of the optical route [16]. A linear polarizer releases only the y-axis component and provides power to the sensor (Fig. 1). Subsequently, the energy is

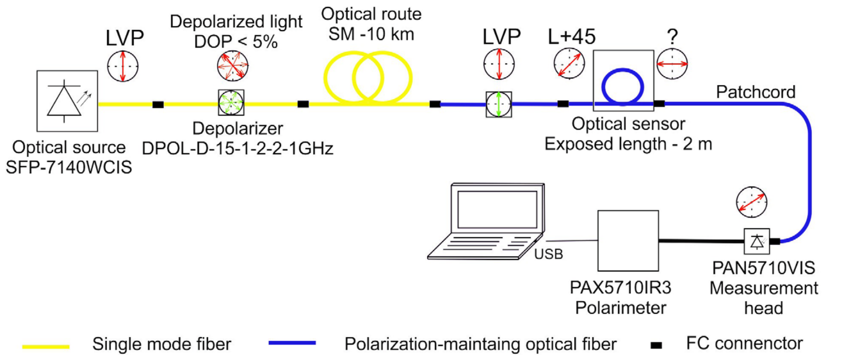

Fig. 1. Workplace scheme with a connected depolarizer and polarimeter.

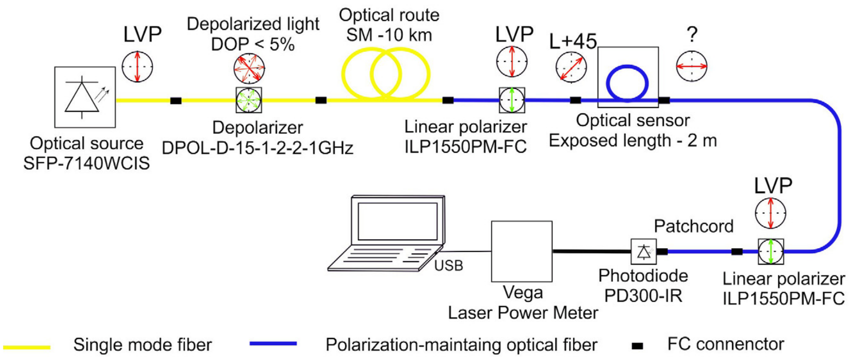

Fig. 2. Workplace scheme with a connected depolarizer and the second linear polarizer.

spread evenly between the x and y planes after passing through the FC connector rotated by +45°. To check if the whole system works, the polarimeter was connected in order to determine the Stokes parameters.

After checking that the entire system works properly, the laser power meter is connected instead of the polarimeter (Fig. 2). The laser power meter is chosen with respect to accuracy, lower cost, and sensitivity, because it measures power in all polarization states, and not only the optical power of the main polarization state as a polarimeter. In this case, without the second linear polarizer, there would not be any changes. The optical power of the incident beam is independent of the immediate state of polarization, so it was necessary to connect the second linear polarizer, which will discharge the power from all axes except the y-axis. Details and principles are explained in [12].

2.2. The use of interference

This approach is the fiber-based version of the Michelson and Mach–Zehnder interferometer, Ref. [21–24] are based on interference too. Linearly polarized light with an approximately 100% degree of polarization travels from the source across the optical route, which causes a slight change in polarization state, due to various physical

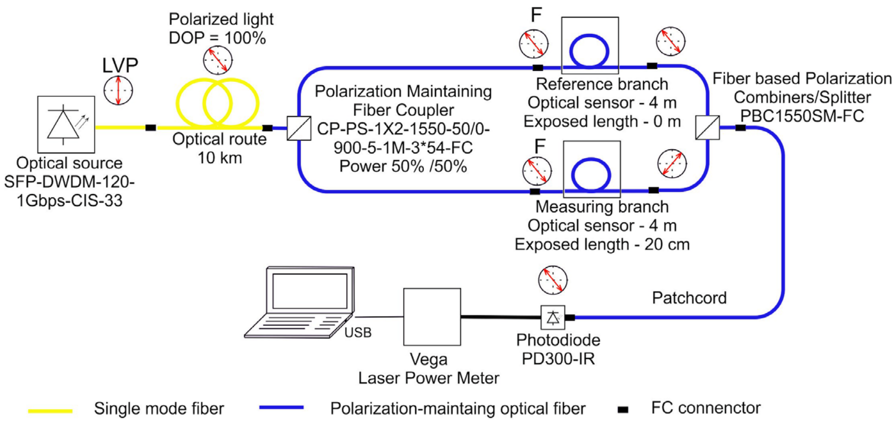

Fig. 3. Workplace scheme with two independent polarization sensors.

influences (Fig. 3). Then a polarization maintaining splitter splits the optical power equally into the measuring branches. The same light travels through both individual sensors, which have the same properties as the input beam but are powered at half the incoming power. An FC connector with the key in the fast axis connects the fiber-optic sensors. There are no changes in the polarization state in the reference branch, because the entire 4 m long fiber is isolated. The measuring branch reacts to changing external influences. Due to its high sensitivity, only 20 cm of a total length of 4 m is exposed. This exposed length was chosen with respect to the expected temperature changes. If the sensor is used to measure minor temperature changes, it is possible to increase the exposed length. The signal from both branches is combined in the polarization combiner [24, 25] into one fiber, which can be easily evaluated and processed on the optical power meter without the need of additional connected components [26, 27].

3. Results and discussions

3.1. Depolarizer

The reaction of Stokes parameters to the temperature change, caused by applying a container with water and ice in the 140th second, is shown in Fig. 4. Stokes 1 and

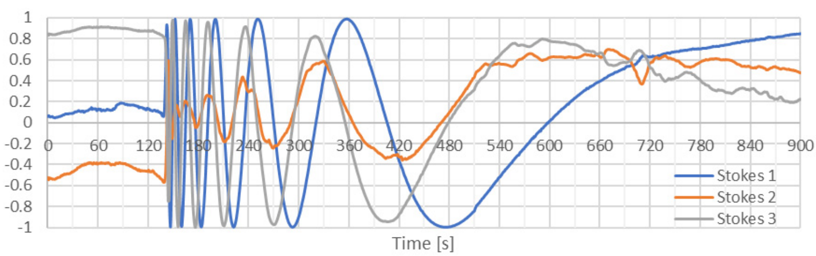

Fig. 4. The reaction of Stokes parameters to the applied container with water and ice (0 °C).

Stokes 3 are almost harmonious, which can be seen as regular movement on all Poincaré sphere. The behaviour of Stokes 2 is not harmonious, so the movement on the sphere is not across the whole surface but is restricted to certain areas. This is possibly caused by the negative influence of connectors or the linear polarizer. This possibly causes connectors or linear polarizer, but despite that fact, Fig. 4 still proves sufficient sensitivity of the sensor to external influences.

The power entering the polarimeter is shown in Fig. 5, where there are no significant changes observed. Changes in the Stokes parameters in Fig. 4 cause mild changes in optical power. This relation between polarization and optical power can be described by mathematical equations. Fluctuations can be caused by a combination of route imperfections, the depolarizer, and signal losses. Therefore, it is necessary to connect another linear polarizer, which drops all polarization states and their power apart from the y-axis polarization, so that power can be evaluated.

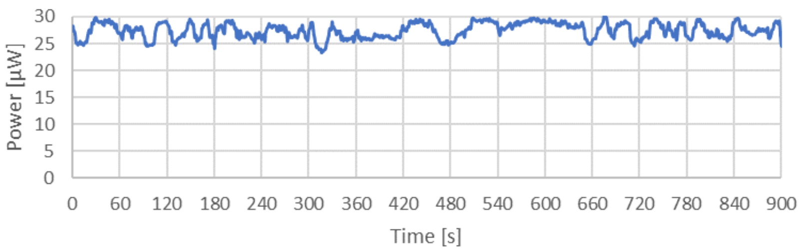

Fig. 5. The sensor's power response to the applied container of water and ice (0 °C) in the circuit with only one linear polarizer.

Figure 6 shows the reaction of the sensor to the applied container with ice at 0 °C in the 140th second. An immediate reaction can be seen. Although the change in polarization due to the applied container should not be visible in the optical, thanks to the second connected linear polarizer, which releases polarization in the y-plane, changes in the output power are significant. In comparison to Fig. 5, Fig. 6 with linear polarizers connected in front and behind, has an almost harmonious course, reaching a maximum value of about 10 μW. Only the y-axis polarization state passes through and carries that power. The remaining power of the different polarization states is

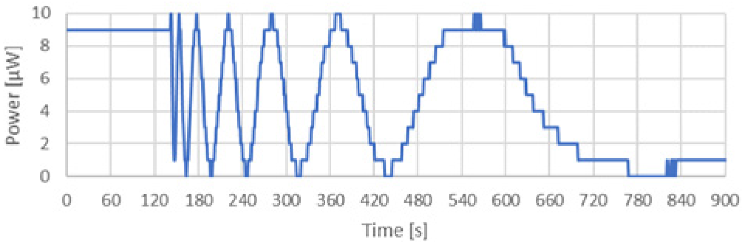

Fig. 6. The power reaction of the sensor to the applied container with water and ice (0 °C) in the circuit with the second linear polarizer.

dropped. Figure 5 shows a mild course of output power, about 27 μW on average, so the difference is about 17 μW. The stair rate was caused by low values and the sensitivity limits of the measuring instrument. During the measurement, the photodiode repeatedly recorded no power, which was reflected in zero values.

3.2. The use of interference

The behaviour of the temperature sensor that was not exposed to any external thermal sources is pictured in Fig. 7. Initially, there are casual changes in the optical power, but it is stabilized by the end of the measurement. The changes could be caused by the presence of an operator near the sensor, or a reaction to smaller temperature changes in the sensor's surroundings.

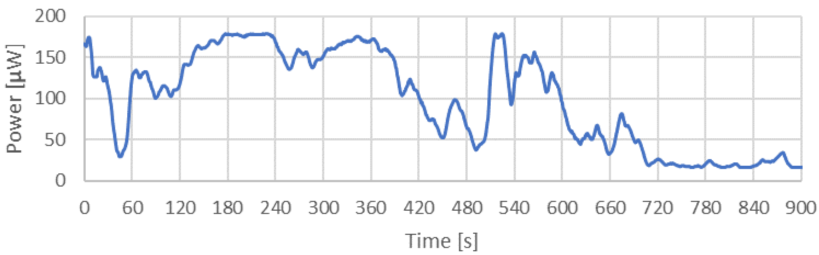

Fig. 7. Power behaviour in the absence of an external thermal source.

Significant changes in optical power are observed when a container with 48 °C water is applied in the 140th second. The whole process is shown in Fig. 8. The sensor reacts immediately. There is an obvious interference that visually resembles the amplitude modulation of two waves. The broadening of the signal is caused by the temperature drop in the applied container of water from the initial 48 °C. The sensor is then exposed to slight temperature changes, which the sensor can still detect and adequately react. It is not an ideal response, but the result can be judged to be a significant change in the ambient surroundings of the sensor, and in the case of object security, it is clear, that something happened. The difference between the initial and final temperature is 24 °C. The explanation of this phenomenon is still under investigation and measurements continue.

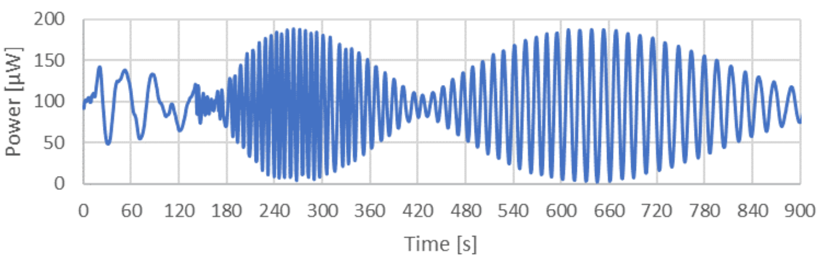

Fig. 8. Power reaction to the applied container with hot water (48 °C).

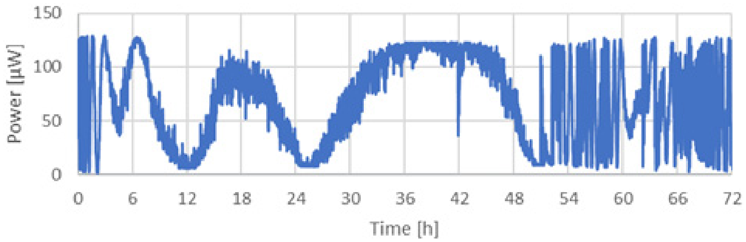

Fig. 9. Long-term measurement.

Figure 9 demonstrates a long-term measurement and the reaction of the fiber-optic sensor to the natural time changes of polarization state in single mode optical route. At first, the visible irregular power value is caused by interference between fiber signals, but due to the sampling of the device, we do not see the change itself in more detail. This irregularity may be caused by the presence of an operator or heating in the room. After six hours, the optical power begins to have a mild, almost harmonious course. Approximately around the 40th hour of measurement, the power on the photodiode reaches its maximum value. There are no significant oscillations, and it can be concluded that the external conditions are constant. A significant change comes around the 50th hour, when the power is at the lowest values during the measurement, but the sensor still responds sufficiently to the external temperature change. This change could be caused, for example by the presence of the operator. It is remarkable that even at the lowest incoming power, the sensor reacts sufficiently and there is no limit to its functionality, in comparison to the connection with the depolarizer, when the quality of the entire measurement is affected by low values of the optical power.

4. Conclusion

The utilization of telecommunication optical routes can have a wide usage in the power supply of fiber-optic polarization sensors. The two proposed approaches come with their own advantages and disadvantages. The first approach involves the use of a depolarizer, which is suitable for short distances and educational laboratory measurements in schools. However, the main disadvantage was found in power management, when the combination of depolarizer, connectors and two linear polarizers allowed the optical power to pass at a small rate. This may cause insufficient sensitivity of the sensor itself and makes the first approach unsuitable.

The second approach, based on interference, is a better solution. There is no wasting of optical power and during long-term measurement, the sensor reacts properly even in the case of the lowest rate. Using two sensors is a disadvantage when one is a reference sensor and does not take place in measurement and must be isolated from the external environment. Here is a new opportunity to connect multiplexers, more sensors, and combinations of both approaches for further research.

Acknowledgement
This work was created with support by project MVČR VI3VS/678.

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Received December 15, 2021
in revised form March 24, 2022