Comparison of Methods for Vibration Detection Using Single-Mode Optical Fiber to Ensuring Information Security

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Abstract: *The paper focuses on the security of fiber optic infrastructures. The main purpose of the paper is present the vibration detection system for unauthorized access to the fiber optic infrastructure detection. For this purpose, measurement of vibrations using the interferometric method and the measurement based on state of polarization changes evaluation is presented. For the measurement own designed systems were used. Both systems are theoretically described and the principles of use are explained. The measurement was performed at an experimental workplace in a laboratory at the university Based on evaluation measurement both systems are compared in term of sensitivity.*

Keywords*:* FIBER, INFORMATION, INTERFEROMETRY, POLARIZATION, SECURITY, VIBRATION

1. Introduction

Information security is one of the fastest growing area of security field today. Entire books are devoted to threats and security used for data transmission networks in an industry [1, 2]. Whereas the optical fibers are widespreadly used today for all data transmission including access networks, metro networks but also for cell phone network infrastructures. It is therefore necessary to deal not only with the protection of the data themselves but also with the protection of infrastructures Based on this need, many research papers have recently been conducted [3, 4] dealing with information leakage or voice information leakage [5]. For this reason, it is appropriate to protect primarily the physical layer of fiber optic networks [6]. Monitoring of networks is the one way to eliminate possible risks [7] and create monitoring systems to protect optical fibers or optical cables, respectively [8].

Based on the above, a polarization change analyzer [9] was was designed and developed, which can be used to secure not only optical infrastructures but also the rooms where the optical fibers terminate. Typically, server rooms or mobile racks in rooms, etc. can be protected. The proposed system will be compared with a simple homodyne Mach-Zehnder interferometer and verification in laboratory condition was performed. The sensitivity of individual systems and the suitability of their implementation in new or existing fiber networks will be discussed.

2. Methods of vibration detection

The method for measuring polarization state changes of the light in single mode optical fiber is based on simple tracking of polarization. Scheme of the system is shown in Fig. 1. The continue waves signal from DFB laser diode is launched into a sensing fiber on one side and the system analyzes the changes in the state of polarization (SOP) on the other side – at the end of the fiber route. The SOP analyzer consists of a polarization beam splitter (PBS), which divides the light into two fibers that maintain polarization. Signals from PBS are detected using a balanced photodetector with a bandwith of 400 MHz. Amplfied electrical signal from the balanced photodetector is then converted from analog to digital form using an analog-to-digital converter (ADC) and acquired for further processing.

The transmission part of system based on interferometric method corresponds to the transmission part of polarization method, i.e. continue wave light signal is launched into the fiber. The signal is then divided into two arms by an optical coupler with a ration 50:50. Measuring arm corresponds to our secured route and the reference arm is isolated from vibrations. Subsequently, the signals from both arms are recombined in another optical coupler and detected by a photodetector. The scheme of a simple interferometer is shown in Fig. 2.

Both of these methods are sensitive to mechanical and acoustic vibrations. In this way, we are able to detect vibrations near the optical fiber along its entire length. It is possible to detect disruption

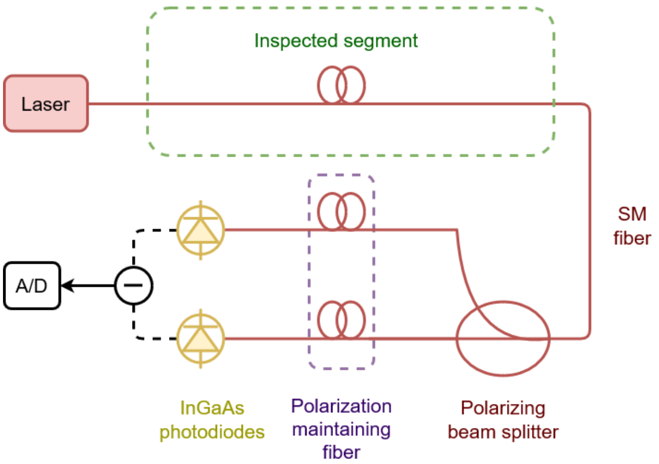

Fig. 1: *Scheme of the system for the detection of SOP changes.*

of secured space a, which is usually a rack or server room, and thus prevent of any unauthorized manipulation with optical fibers, which can significantly increases the security of transmitted information before possible eavesdropping. The fiber can also be eavesdropped on the route but since these systems are able to detect vibrations along its entire length, it is possible to track manipulation at any location. The only disadvantage of both systems is that it is not possible to locate in which part of the fiber or cable the manipulation takes place. It is only possible to determine the fact that the fibers are being manipulated.

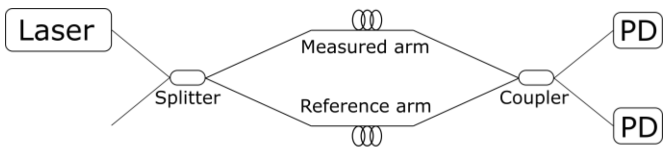

Fig. 2: *Schematic of the Mach-Zehnder fiber interferometer [10].*

3. Evaluation measurement setup

The comparison of sensitivity of the interferometer and the polarization state analyzer can be done in two ways. The first one is to create standardized tests and measure individual methods separately. The second and much simpler way is to create a setup combining both methods and evaluate systems in the same conditions. The scheme can be seen in Fig. 3. Both methods use the same laser diode source and one ADC. The light emitted by the laser is split by a 50:50 coupler into the sensing fiber and the reference fiber of the interferometer system. The reference fiber has the same length as the sensing fiber and is wounded inside the analyzer system. Part of the signal at the end of the route is split and used for polarization analysis... Data from photodetectors of both systems are then sent to the storage server via Ethernet. Since both systems are sampled at 8 kS/s, the HDF5 data storage format was chosen, which is suitable for large data files. In fact, MyRIO, which is used for data acquisition samples each system at a frequency seven times greater, i.e., 56 kS/s, and the samples are then averaged directly in MyRIO to the final 8 kS/s.

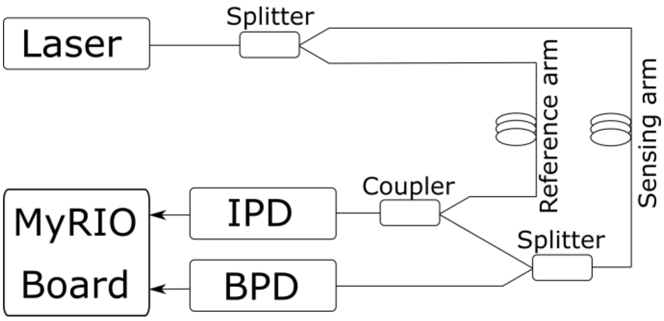

Fig. 3: *Scheme evaluation setup with Mach-Zehnder interferometer and SOP analyzer.*

The measured fiber used for the evaluation measurement led from the rack cabinet and was laid on the ceiling in the laboratory room; see Fig. 4. The laboratory is equipped with tables, chairs, and cabinets. The measurement was aimed to testing the possible detection of vibrations caused by the opening of the entrance door to the room and the opening of the rack unit door.

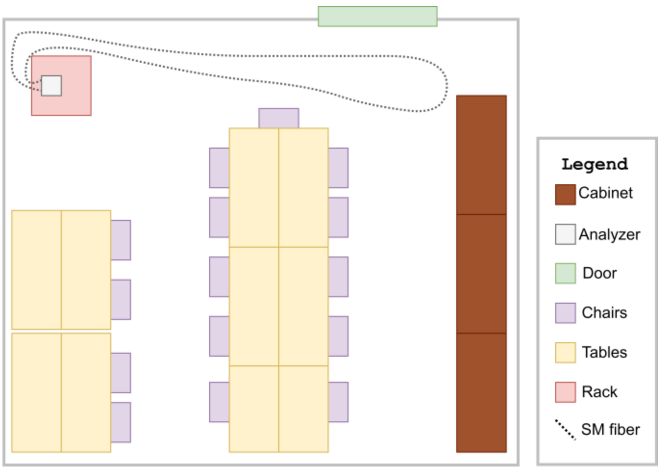

Fig. 4: *Scheme of a laboratory for intrusion testing in a server room equipped with analyzers and SM fiber.*

4. Results

The measurement results can be seen in Fig. 5 and 6, respectively. Fig. 5 shows the waveforms measured when the rack door is manipulated. Specifically, there are 3 events caused of opening and closing rack doors. It can be seen from the waveforms that such a security breach can be detected by the SOP analyzer system and by the interferometer. Furthermore, it can be noted that measurements with a Mach-Zehnder interferometer are much more sensitive than measurements with SOP analyzer. The signals are set to rest, in this case, it can be seen that the polarimeter settles faster, which is due to the high sensitivity of the interferometer and the vibration of the rack by closing the door.

Fig. 6 shows the opening and closing of the laboratory door (the door is marked by green color in Fig. 4). Amplitude variations are smaller and idle states faster compare to results presented in Fig. 5. This is due to the much lower intensity of the vibrations, because the rack door is close to the optical fibers, the laboratory door is more distant and does not have direct contact with the optical fiber that is located on the ceiling. In any case, based on the results it can be stated that it is possible to secure areas with optical fibers with both systems. Areas prone to unwanted cable handling and information leakage can be secured.

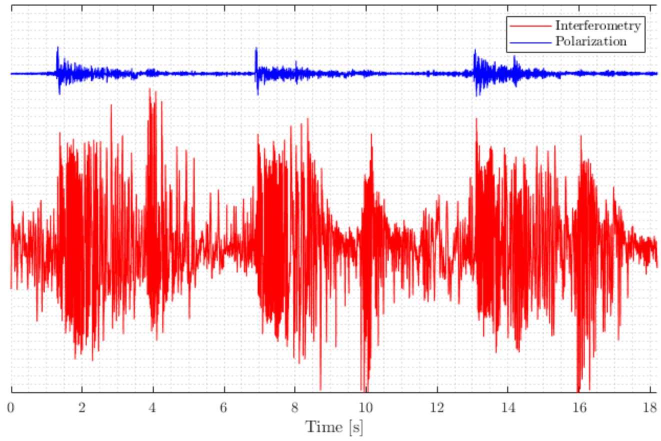

Fig. 5: *Comparison of methods. Vibration caused by opening and closing rack doors.*

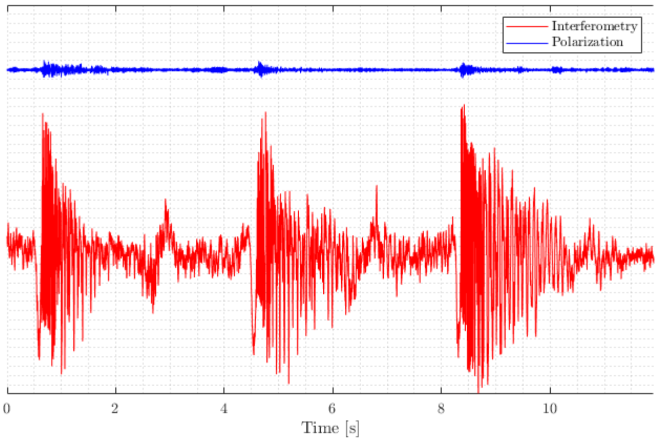

Fig. 6: *Comparison of methods. Vibration caused by opening and closing entrance doors.*

5. Discussion

On the basis of the measurement results, it is possible to conclude that the interferometric method is much more sensitive for vibration detection, which can be counterproductive, especially in the case of securing the fibers against unauthorized manipulation. Most fiber optic cables in buildings are mounted in ceilings, walls, or under floors. As a result, these are exposed to vibrations caused by normal operations in buildings such as people walking, etc.

Another advantage of using the SOP changes analyzer is the possible direct implementation into existing fiber-optic infrastructures. It is common practice to oversize the infrastructure, where due to few necessary optical connections, standard cables with 12 or 24 fibers are mounted. The SOP changes analyzer can therefore be connected directly to an unused fiber and thus secure both the access points and the cable where all fibers are in the same armor and outside jacket. In case of interferometer system, it is always necessary to add an additional reference arm, which is often problematic in the existing infrastructure.

If the existing infrastructure is fully utilized, it is possible to use, for example, wavelength division multiplexing. In this case, one wavelength or wavelength multiplex can be supplemented by another wavelength. This new signal on dedicated wavelength is only used to for SOP changes evaluation. However, this is used only in the case when the all fibers in the cable is used, which is a less common situation in practice. As part of the verification of the functionality of the systems, the detection of other events that may pose risks was also tested. These include fiber disconnection, direct fiber handling, quick fiber link reconnection, etc. The possible detection of all these events and their description is beyond the aim of this paper.

6. Conclusion

The paper presents the importance of information security and describes some of the risks arising from the optical transmission. Furthermore, the possibilities of monitoring systems for measuring vibrations are discussed. The paper deals with the Mach-Zehnder interferometer and the SOP changes analyzer. Individual systems are described in detail. Subsequently, the paper deals with the evaluation setup, which combines both systems together to reduce the measurement error. The setup is shown schematically and the laboratory in which the measurement was performed is described.

From the results, it can be concluded that both methods are able to detect vibrations. The interferometric method appears to be more sensitive. SOP changes analyzer is more suitable for deployment in existing infrastructure due to its simplicity and sensitivity. The interferometric system is rather unsuitable due to the need to add a reference fiber that must be isolated from the vibrations. Our developed SOP changes analyzer can be directly deployed in the existing infrastructure.

Funding

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7. References

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