

1 Proceedings

## 2 Computer support of analysis optical spectra measurements

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7 † Presented at the 8th International Symposium on Sensor Science, 17–26 May 2021; Available online:  
8 <https://i3s2021dresden.sciforum.net/>.

9 **Abstract:** Verification of measurement errors has a big impact on assessment of accuracy of  
10 conducted measurements and obtained results. In many cases computer simulation results are  
11 compared with measurement results in order to evaluate measurement errors. The purpose of our  
12 research was to check the accuracy of measurements made with Fabry-Perot interferometer  
13 working in the transmission mode. In measurement setup, a 1310 nm superluminescent diode  
14 light source, single-mode optical fibres and optical spectrum analyser were used. Influence of  
15 length of resonating cavity and refractive index on the envelope of optical spectrum was  
16 investigated. A created program that models envelope of the optical spectrum on the basis of:  
17 length of the resonating cavity, refractive index and light source output spectral characteristic,  
18 which in simulation, was assumed to have shape of Gaussian distribution. After the simulation the  
19 program compares simulated and measured optical spectrum. The comparison of simulated and  
20 measured optical spectra proved to be challenging due to the shift in the position of the central  
21 peak between the simulated and measured optical spectrum. There are two ways to perform  
22 model fitting: by adjusting the position of central peaks or minimums next to the central peak. It  
23 was observed, that the second solution was more optimal and was implemented in the program.

24 **Keywords:** sensors, fiber-optic, interferometer,  
25

### 26 1. Introduction

27 Nowadays fiber-optic sensors based on the Fabry-Perot interferometer construction  
28 have become popular. They ensure stable and repeatable measurements [1]. They can be  
29 placed in hard-to-reach places because they have small physical dimensions [2].  
30 Moreover, they are resistant to electromagnetic waves [3]. Standard telecommunication  
31 optical fibers can be used for their construction which potentially reduces the cost of  
32 sensor production. Fiber-optic sensors can be used to measure physical parameters such  
33 as temperature [4], displacement [5] and refractive index [6]. They can be found in many  
34 fields of science and technology, including biological [7] and chemical research [8]

35 An important issue in metrology is verification of the accuracy of the  
36 measurements when analyzing the results [9]. Imprecise measurements can lead to  
37 erroneous conclusions after the analysis and interpretation of such defective data.  
38 However, detection of errors that may have occurred while performing measurements is  
39 possible. These errors may result from the finite precision of the devices used to set the  
40 width of the cavity of the interferometer or from parallax error. Some of them may  
41 result from imperfections of devices, e.g. fluctuation of the light source. Depending on  
42 the cause of their occurrence, various types of errors can be distinguished, such as  
43 outliers, systematic and random errors. However, they can all have a significant impact  
44 on the accuracy of the measurements. The accuracy of interferometric measurements  
45 depends mainly on the parameters of the interferometer cavity. These are the width of

26 **Citation:** Lastname, F.; Lastname, F.;  
27 Lastname, F. Title. *Eng. Proc.* **2021**, *3*,  
28 x. <https://doi.org/10.3390/xxxxx>

31 Published: date

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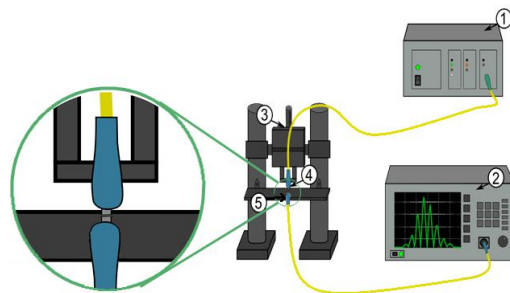
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1 the cavity and the refractive index of its filling medium. Checking the accuracy allows  
2 determining the exact parameters of the measurements, which may be crucial when  
3 examining the influence of slight changes in the refractive index on the obtained results.

4 The purpose of our research was to find a way to check the accuracy of  
5 measurements performed with a Fabry-Perot interferometer.

## 6 2. Materials and Methods

7 Figure 1 shows the setup that was used for the measurements. It was a fiber-optic  
8 implementation of the Fabry-Perot interferometer working in the transmission mode.  
9 Two single-mode optical fibers (SMF-28 Ultra Optical Fiber, Corning, U.S.A ) were used.  
10 They are commercially available and can be applied in communication, meaning that we  
11 could easily connect our system to the existing network infrastructure. The first  
12 fragment of the fiber connected a 1310 nm superluminescent diode (SLD1310-36,  
13 FiberLabs Inc., Japan) with a micromechanical system, and the second one connected the  
14 system with the optical spectrum analyzer (Ando AQ 6319, Yokogawa, Japan). The use  
15 of a micromechanical system made it possible to set the resonance cavity with an  
16 accuracy of 5  $\mu\text{m}$ .

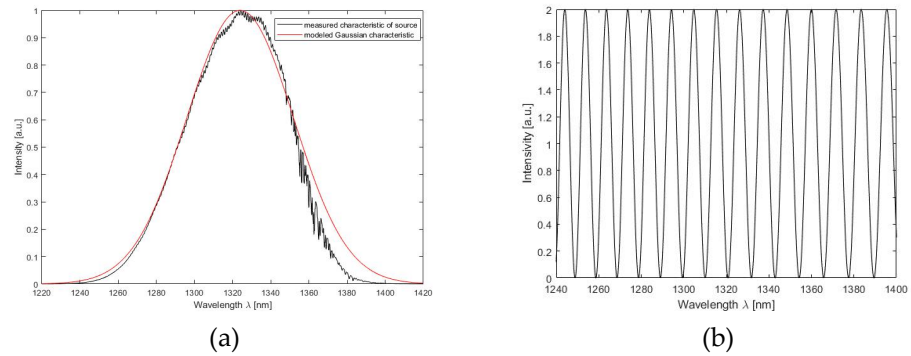


17  
18 **Figure 1.** Measurement set up, where 1- light source working at the central wavelength of 1310 nm,  
19 2- optical spectrum analyzer, 3- a micromechanical setup, 4- two single-mode optical fibers.

20 This system was used to study the effect of changing the width of the resonance  
21 cavity and changing the refractive index of the substance filling this cavity on the  
22 observed optical spectra.

## 23 3. Results

Generating a mathematical model of the optical spectrum and comparing it with the measured optical spectrum is a way to check the accuracy of the interferometric measurement. To create a spectral model, the spectral characteristic of the light source that was used for the measurements was used. To achieve better results, this spectrum was assumed to have an ideal shape of a Gaussian distribution [10]. The comparison between the spectrum characteristics is shown in Figure 2a.



**Figure 2.** Base elements of the model: **(a)** modeling a light source as an ideal Gaussian distribution; **(b)** model of interferometer transmission.

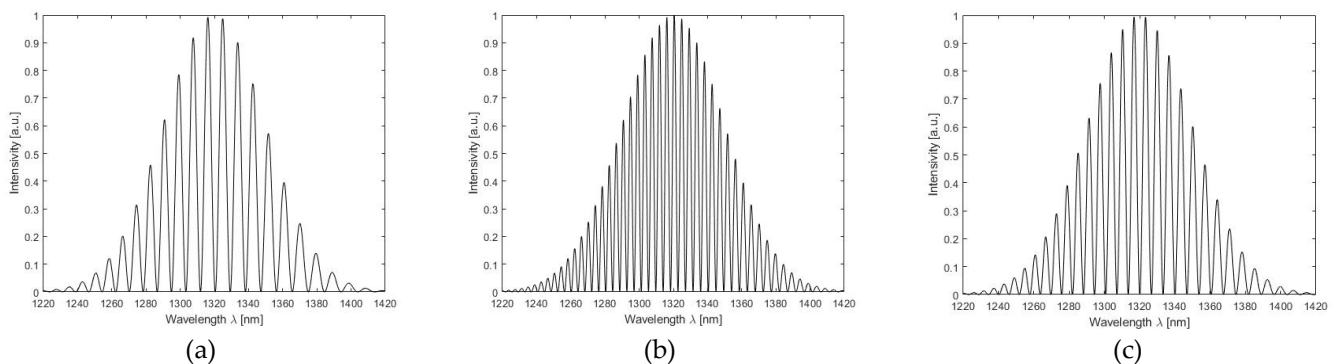
The measured characteristic differs from the modeled. This is due to errors at the stage of production of the light source and imperfections of its elements. The simple mathematical model that was used ignores these drawbacks.

Then, the transmission signal of the interferogram was modeled according to Formula 1 [11]:

$$T = 1 + \cos \frac{4\pi \times n \times l}{\lambda}, \quad (1)$$

where  $n$  is the refractive index,  $l$  is the cavity length and  $\lambda$  is the wavelength. The modeled optical spectrum of the transmission signal is shown in Figure 2b.

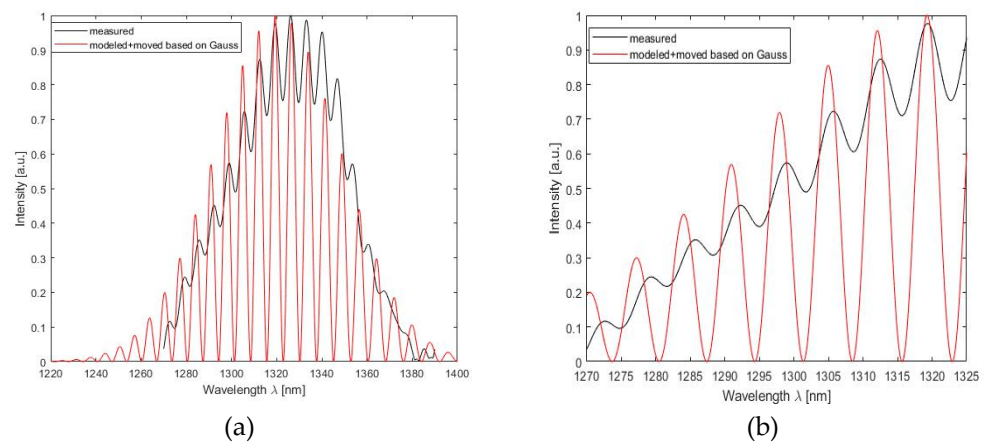
In the next step, the modeled signals of the source and the transmitting signals of the interferometer were multiplied. The shape of obtained optical spectrum depends on the source model used, the value of the resonance cavity width, and the refractive index. Since only one light source was used in this research, the focus was on changing the remaining parameters. Figure 4 shows the obtained models depending on the value of the width of the cavity and its refractive index.



**Figure 4.** Prepared models of interferograms with parameters equal: **(a)** refractive index 1.0003 (air) and length of cavity 100 μm; **(b)** refractive index 1.0003 (air) and length of cavity 200 μm; **(c)** refractive index 1.33 (water) and length of cavity 100 μm.

To check the accuracy of the performed measurements, the modelled optical spectra were compared with the measured ones. For this purpose, the position of the simulated

optical spectrum was shifted to have the minima in the same position on the x-axis. The result of this shift is shown in Figure 5a.



**Figure 5.** The comparison of simulated and measured interferograms: **(a)** full interferograms; **(b)** the region with the best fitting.

Good coverage of the modeled optical spectrum with the measured optical spectrum was achieved. The best fit appeared on the rising slope of the graphs as shown in Figure 5b. This leads to the conclusion that the proposed method of spectra modelling can be a useful tool for the assessment of the measurement results accuracy.

#### 4. Conclusions

The created modeling program is easy to use. It can be used for a light source of any wavelength. It allows you to simulate changes in the refractive index and the width of the resonant cavity. It allows you to compare the model and the measured spectrum characteristics. It was created for modeling measurements made with a Fabry-Perot interferometer operating in transmission or reflection mode, but it is not excluded to simulate optical spectra from other double-beam interferometers.

In summary, the program is very user-friendly and allows you to check the accuracy of the measurements carried out and to determine the measurement errors. Moreover, it facilitates the determination of the width of the resonance cavity and the value of the refractive index. The model can be used as a control or reference measurement.

**Acknowledgments:** The authors acknowledge the financial support from the DS Programs of the Faculty of Electronics, Telecommunications and Informatics of the Gdańsk University of Technology. Financial support of these studies from Gdańsk University of Technology by the 4/2020/IDUB/III.4.1/Tc and 8/2020/IDUB/III.4.1/Tc grant under the – Technetium EIRU program is gratefully acknowledged.

#### References

1. D. Tosi, S. Poeggel, G. Leen, E. Lewis, Adaptive filter-based interrogation of high-sensitivity fiber optic Fabry-Perot interferometry sensors, *Sensors Actuators A Phys.* **2014**, 206,144–150, doi: 10.1016/j.sna.2013.12.010.
2. Jin Li, Yan-nan Wang, Jun-tong Yang, Compact Fabry-Perot microfiber interferometer temperature probe with closed end face, *Measurement*, **2021**,178, doi: 10.1016/j.measurement.2021.109391
3. Xinlei Zhou, Qingxu Yu, Wei Peng, Fiber-optic Fabry-Perot pressure sensor for down-hole application, *Opt. and Las. in Eng.*, **2019**, 121, 289–299, doi:10.1016/j.optlaseng.2019.04.028
4. A. Leal-Junior, A. Frizera-Netoc, C. Marques, M.J. Pontes, A polymer optical fiber temperature sensor based on material features, *Sensors (Basel)*. **2018**, 18, doi: 10.3390/s18010301.
5. D. Milewska, K. Karpienko, M. Jędrzejewska-Szczerska, Application of thin diamond films in low-coherence fiber-optic Fabry Perot displacement sensor, *Diam. Relat. Mater.* **2016**, **64**, 169–176, doi: 10.1016/j.diamond.2016.02.015.
6. M. Kosowska, D. Majchrowicz, K.J. Sankaran, M. Ficek, K. Haenen, M. Szczerska, Doped nanocrystalline diamond films as reflective layers for fiber-optic sensors of refractive index of liquids, *Materials (Basel)*. **2019**, 12 doi: 10.3390/ma12132124.

- 1 7. A.B. Socorro-Leránóz, D. Santano, I. Del Villar, I.R. Matias, Trends in the design of wavelength-based optical fibre biosensors  
2 (2008–2018), *Biosen. & Bioelec.*: X, **2019**, 1, doi: 10.1016/j.biosx.2019.100015.
- 3 8. M. Jedrzejewska-Szczerska, Response of a new low-coherence Fabry-Perot sensor to hematocrit levels in human blood,  
4 *Sensors* **2014**, *14*, 6965–6976; doi: 10.3390/s140406965.
- 5 9. A.G. Olszak; J. Schmit .High-stability white-light interferometry with reference signal for real-time correction of scanning  
6 errors, *Opt.Eng.* *42*(1), **2003**, doi: 10.1117/1.1523942.
- 7 10. M. Jedrzejewska-Szczerska, Shaping coherence function of sources used in low-coherent measurement techniques. *Eur. Phys. J.*  
8 *Spec. Top.* *144*, **2007**, 203–208, doi: 10.1140/epjst/e2007-00128-5.
- 9 11. S. A. Egorov, A. N. Mamaev, A. S. Polyantsev, Spectral signal processing in intrinsic interferometric sensors based on  
10 birefringent polarization-maintaining optical fibers, *Jour. of Light. Tech.*, **1995**, *13*, 1231–1236, doi: 10.1109/50.400694.
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