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Application of Microwave based Electrical Read-Out of Fiber Bragg Gratings in Thermometry

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Summary:

The evaluation of optical fiber sensors is conventionally carried out optically by analyzing the amplitude of the transmitted or the reflected light. A novel approach in the form of an electrical read-out was proposed in a former contribution [1]. The underlying concept is to interrogate the optical sensor with an RF modulated laser and carry out a full electrical analysis of the resulting RF signal. The applicability of this electrical read-out method for temperature measurements is investigated in this paper.

Keywords: optical fiber sensors, RF modulated laser, electrical analysis, temperature, radio-over-fiber

Introduction

Optical fiber sensors are available for many purposes. Especially in applications with restricted accessibility, difficulties to integrate the read-out equipment can be overcome by using Radio-over-Fiber (RoF) technology. While the evaluation of optical fiber sensors is conventionally carried out optically by analyzing the amplitude or spectrum of either the transmitted or the reflected light, a novel approach in the form of an electrical read-out was discussed in a former contribution [1]. The underlying concept is to interrogate the optical sensor with an RF modulated laser and carry out a full electrical analysis (amplitude *and* phase) of the resulting RF signal, which is changed by the sensor's characteristics. Due to the inherent presence of an RF signal in this scheme, it is particularly suitable for RoF measurement setups. As up to now, only the theoretical concept of measurements based on the electrical read-out method has been considered, a first approach of quantitative measurements is pursued in this work.

Thermometry based on optical fiber sensors

One of the most frequently measured quantities is temperature. Different types of sensors are suitable to accomplish this task, among these are optical sensors. In comparison to resistance thermometers, their main advantages are the resilience against electromagnetic interference and mechanical shock [2]. On the downside, the measurement uncertainty of optical temperature sensors is around 500 mK whereas resistance temperature sensors achieve 10 mK or better [2]. Nonetheless, the demand for resilient sensors led to the development of a variety of optical temperature sensing principles. Well investigated ones rely on Fiber Bragg Gratings (FBG). Such sensors are still subject to new studies [3] while being already commercially available [4]. For that reason, this paper focuses on FBG based temperature sensing.

Setup and measurements

The experimental setup (Fig. 1) links closely to the first study in the field of el. read-out [1]. The sensor is a cos-shape apodized FBG (length: 25 mm, stop-band: 1537,67 nm ± 75 pm). It is thermally attached to a thermoelectric cooler (TEC). A forward calibration of the entire setup is performed at the center wavelength (CWL) of the FBG. The sensor characteristic is then recorded at a controlled temperature of 22.0 °C by a scan with the tunable laser source (TLS) (span: CWL ± 200 pm, step width: 1 pm). The sweeps on the VNA (2.4 to 2.5 GHz) cover the ISM band ensuring compatibility with RoF setups (power: -20 dBm, RBW: 500 Hz, 1001 pts). Further reference curves are acquired at [21, 23, 24, 25] °C with otherwise identical settings.

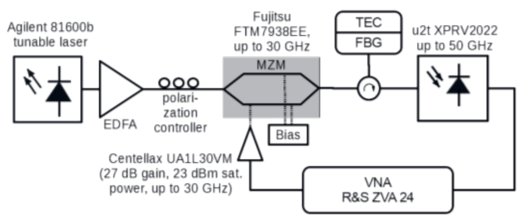

Fig. 1. Block diagram of the experimental setup.

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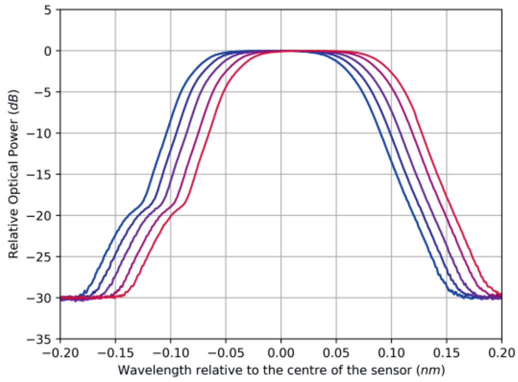

Fig. 2. Electrically derived FBG filter characteristic from 21 °C (blue) to 25 °C (red).

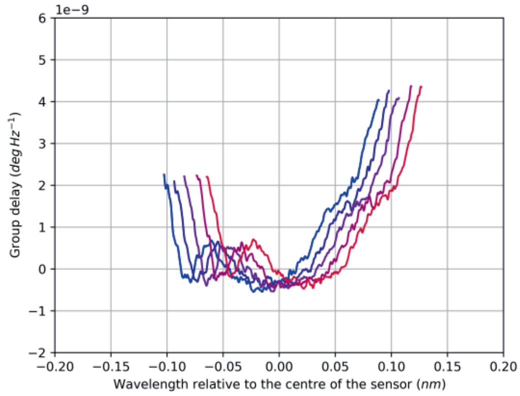

Fig. 3. Group delay characteristic of FBG derived from el. phase from 21 °C (blue) to 25 °C (red).

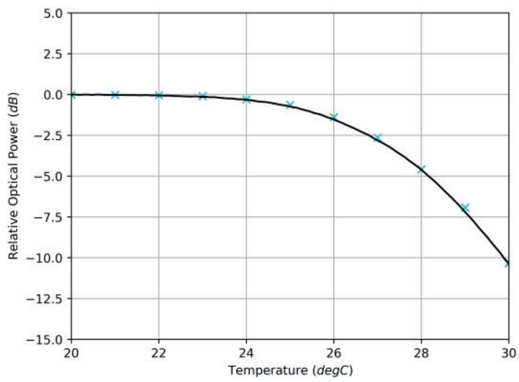

Fig. 4. Relative optical power at different temperatures vs. reference derived from 22°C curve (black).

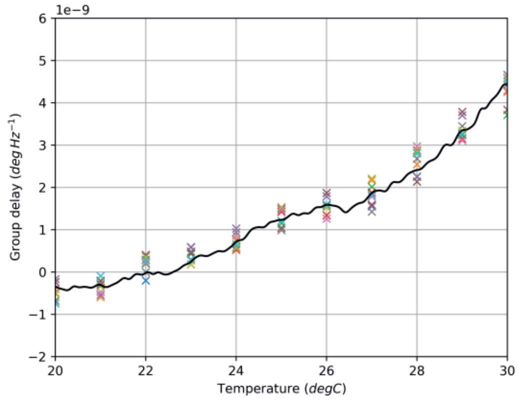

Fig. 5. Group delay at different temperatures vs. reference derived from 22°C curve (black).

Afterwards, the sensor is heated to various temperatures and the actual measurements are performed by single sweeps on the VNA at each temperature while the TLS remains fixed at 1537.75 nm. Each measurement consists of ten sub-measurements at an interval of 5 s.

Evaluation and Results

For each complex S21 curve of the reference sweeps, the arithmetic mean of the magnitude and the slope of the phase (1st deg. polynomial fit) are calculated across the complete el. BW. The results for the absorption characteristic are shown in Fig. 2. From the visible temperature induced wavelength shift, a temperature coefficient of 9.7 pm/K is resulting, which agrees with other studies pointing out a value of ~ 10 pm/K [5]. In Fig. 3, the group delay characteristics (calculated from the phase slopes) are shown; they lead to the same coefficient value. The single temperature measurements are evaluated likewise. Figs. 4 and 5 show these results and compare them to the related reference characteristics. Both curves are fitted well while the group delay measurements are showing a significantly larger uncertainty of up to 2 K.

Conclusions

Essentially, the temperature reading from the optical power equals the conventional read-out method. In line with this, the results are accurate. Compared to this benchmark, the group delay based measurements possess greater uncertainty but are independent from power fluctuations. Anyway, this study could successfully demonstrate the fundamental suitability of the electrical read-out method for metrology.

Acknowledgement

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