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Design System of Optical Heterodyne Detection Based on Temperature Sensor

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Abstract: Optical Heterodyne Detection (OHD) technique is based on two separate sources with optical interference between them. The optical signal from a specific light source is compared with a separate reference signal from another source. The *Fiber Bragg grating* (FBG) reflect a specific wavelength λ_B and transmit the other wavelengths within the laser source spectral. This is achieved by changing the refractive index generated by periodic variation of optical fiber core, which reflect a specific wavelength, so FBG can be used to withhold a certain wavelength and allow other wavelengths to transmit. In this paper, a new method of an OHD has been designed using Optisystem software. Optical fiber as a temperature sensor element with single source and two FBGs have used in this system. the first FBG used as a tunable source and the other has used as a sensing element. The two optical signals have been combined utilizing a photodetector. It has a linear response to the light energy, while having a quadratic response with the amplitude of the electromagnetic field. The results show that the beat frequency shift has a linear response to the temperature with sensitivity about 2.24 GHz/C°.

1. Introduction

In recent years, the OHD has won the exceptional attraction, with reason of its features such as an optical system. OHD is an advance technique with regard to communications [1], and sensing like temperature [2], strain [3], pressure [4], bending [5], current [6], nanoelectronic [7] sensors. The heterodyne detection systems were implemented to detect the phase difference between two signals that are guided by reference and sensing arms, which is caused by some environment changes [8].

An OHD was studied and demonstrated by many researchers using many techniques.

In 2017, Gonzalez has used heterodyne technique as a strain sensor utilizing single source and dual FBG as sensing and reference elements [3]. Huanhuan was demonstrated a new way to truly measure the shifting in phase originated from external vibration using heterodyne phase-sensitive optical time-domain reflectometer (ϕ -OTDR) in 2018 [9]. While in 2018 Liangcheng was achieved a high-resolution temperature sensor utilizing OHD by effect of the narrow linewidth characteristic of a single-frequency fiber laser [5]. In 2018 Shehab presents a single laser source with FBG as a tunable source to achieved OHD with single mode fiber as a sensing arm [10]. In current work, two FBG one of them introduced as laser source and the other used as a sensing element.

2. Theoretical Concepts of Optical Heterodyne Detection

The OHD is a kind of interferometry detection that used to detect phase shift between two waves. Beat frequency (f_B) which is a new generated frequency due to mix reference and sensing signals. The difference between them is caused by some environmental changes around the sensing arm.

$$f_B = \Delta f = f_S - f_R \quad (1)$$



Where f_S and f_R are sensing frequency and reference frequency respectively. The output electromagnetic waves of the interferometer are combined in a photodetector then the generated photocurrent is given by the total electric field square, as shown in the subsequent equation [9];

$$I(t) = |A_R \cos(\omega_R t + \phi_R) + A_S \cos(\omega_S t + \phi_S)|^2 \quad (2)$$

Where the both subscripts R and S point out that each parameter represent both of the reference and sensing wave respectively. A represent the amplitude of reference and sensing waves, ω is the angular frequency, ϕ is the phase of waves.

The relative phase is given by;

$$\phi = \frac{2\pi nL}{\lambda} \quad (3)$$

Where L is sensing element length, n is refractive index.

Phase difference represent the sensing signal is subtracted from reference signal as the following equation shows [9];

$$\Delta\phi = \phi_R - \phi_S \quad (4)$$

Phase difference is obtained by;

$$\Delta\phi = \frac{2\pi Ln\Delta\lambda}{\lambda_R \lambda_S} \quad (5)$$

Where $\lambda_S = \lambda_B = 2n_{eff}\Lambda$ where n_{eff} is effective refractive index, Λ represents the distance between the gratings [11].

3. System model

The phase shift is a function of wavelength shift in the system shown in Figure 1. The system is consisting of laser light, four optical couplers C_1 , C_2 , C_3 and C_4 , photodiode (PD), Two uniform Fiber Bragg Gratings and Oscilloscope. Here FBG₁ utilized as a tunable source, where it can reflect incident signal, FBG₂ used as a sensing element in order to achieve heterodyne in output wave. The first coupler C_1 split the launched light into two beams along reference arm and FBG₁. The second beam reflected from FBG₁ which represents a tunable source. FBG₂ receive FBG₁ signal and forward it to C_4 , reference arm signal and reflected signal of FBG₂ via C_3 will be combined using C_4 . Finally, the output waves were processed using photodiode. Output f_B can be measured using Oscilloscope. The difference in phase between signals is measured by OHD.

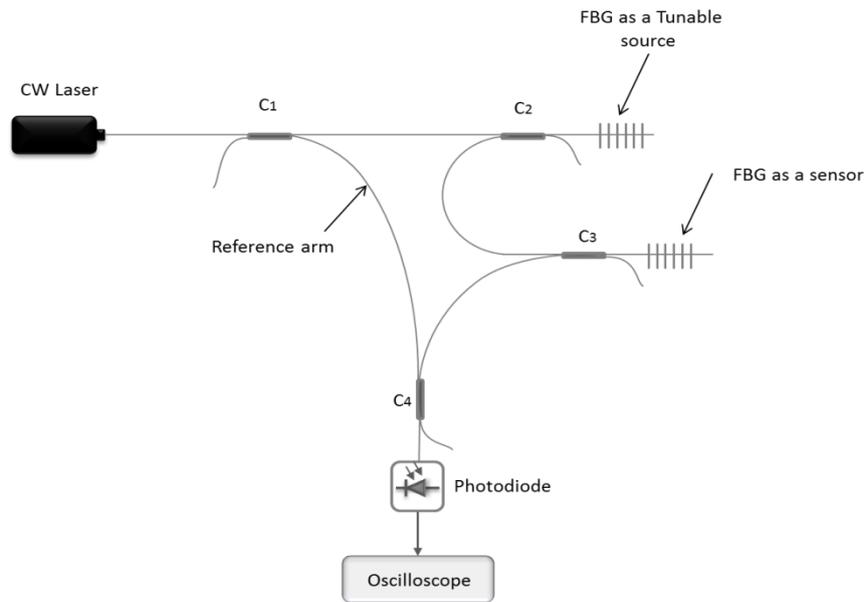


Figure 1. Optical heterodyne detection system

The phase shift occurs due to the shifting in FBG₂ wavelength caused by temperature changes. The output generated signals are measured in GHz.

4. Results and Discussion

The results by using the proposed technique has been achieved. Figure 2 shows sensing options of uniform FBG. The temperature range changes from (20 to 100) °C. Here 20°C has used as a reference temperature (room temperature), the reference wavelength is 1550nm. The strain effects have neglected, thermal expansion coefficient and thermo-optic coefficient have set to $0.55 \cdot 10^{-6} / ^\circ\text{C}$ and $8.6 \cdot 10^{-6} / ^\circ\text{C}$ respectively.

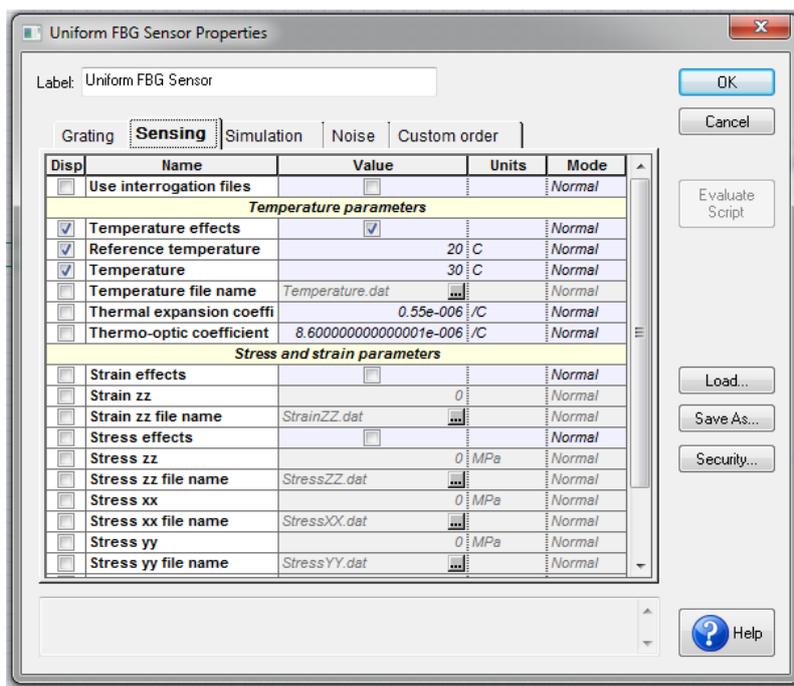


Figure 2. sensing options window.

The results by using the proposed technique has been achieved. Figure 3 shows wavelength shift for different values of temperature. The difference between wavelength represent f_B .

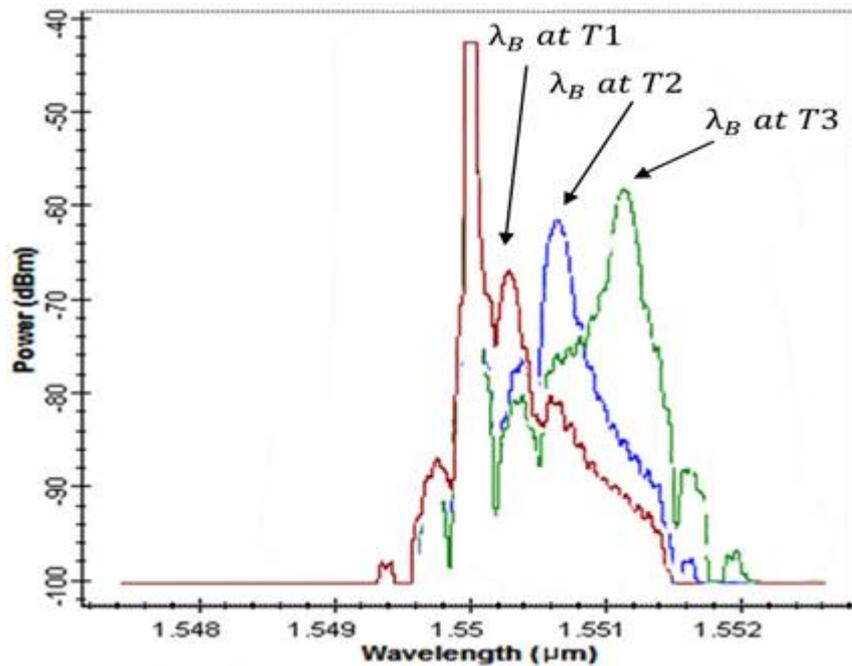


Figure 3. wavelength shift over ΔT

The system results have been achieved as shown in Figure (4). As is evident the results show up the beat frequency generated from mix the sensing and reference signals has a frequency shift because of shifting in sensing wave.

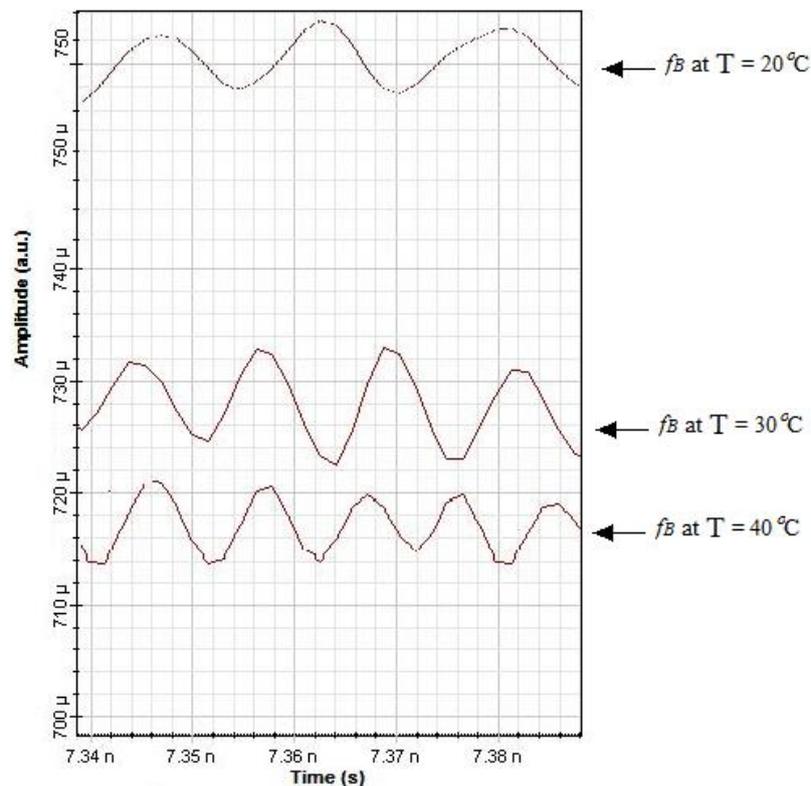


Figure 4. f_B at T about (20, 30 and 40) °C.

The f_B shift over temperature have range from (0 to 100), it seen as a linear function. f_B increases with the rate of about 2.24 GHz/C° as illustrated in Figure 5.

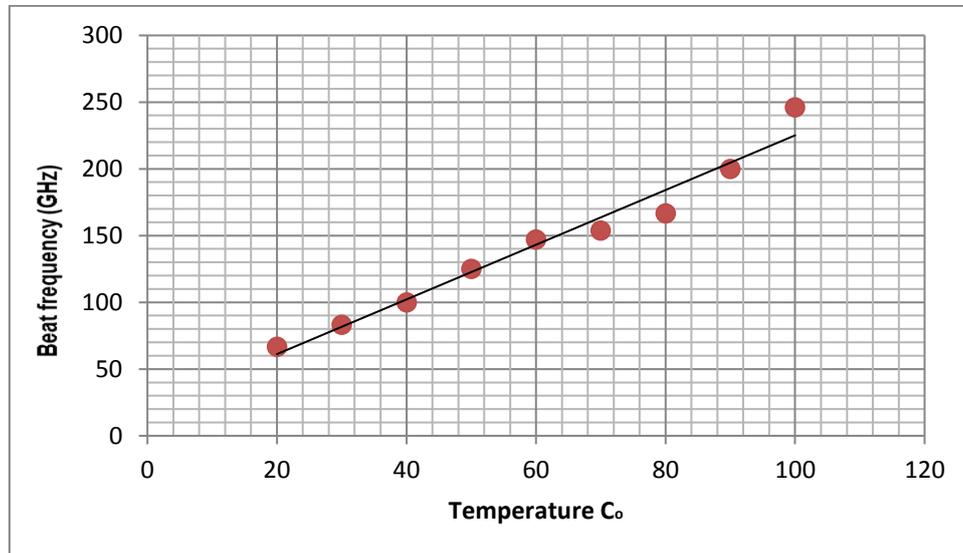


Figure 5. Relationship between f_B and T.

5. Conclusion

In this paper a new method was introduced using laser light and two FBGs. It shows many advantages over conventional techniques such as a high response with long live but with low resolution. Using OHD helps to detect the output without any extra devices such as optical spectrum analyzer. The sensitivity was achieved in this work about 2.24 GHz/C°. The system results show that the current methods can do improvement with respect to another conventional technique. The shifting in beat frequency of conventional systems are measured in GHz. It will award the ability to measure output signals using conventional detectors, such as photodiodes. The conventional systems need OSA to measure output signal, this will lead to more cost and complexity, as opposed to the current system which offered low cost and less complexity.

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