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Design and construction of visible light Instantaneous wavelength measurement device

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Abstract- This paper presents a method for measuring the wavelength of visible light. Many laboratory and industrial applications require a wavelength measurement system. Wavelength sensing devices in the visible and infrared spectrum are expensive and bulky. As a result, the use of wavelength sensors has been neglected in many applications. In this research, a practical design and construction of a wavelength measuring device with a simple electro-optical method has been investigated. Cost is much lower than the existing spectrometers, portability and continuous output are the features of this system. The system's response range is from 750 to 950 nm. Increasing wavelength spectral range is possible using a different optical filter. The key to solving the problem is the unique amount of light passing through a filter for a specific wavelength. When the signal reaches the system with a specific wavelength, as the amount of input light attenuation is a unique for each wavelength, the wavelength (frequency) of the received signal can be determined by the amount of light attenuation in comparison to reference light. Then the wavelength can be declared by a processor. Depending on the measured wavelength, color detection can be done based on the wavelength.

Keywords: Instantaneous frequency measurement; Wavelength measurement; Frequency measurement; Spectrometry

1. Introduction

Measuring the wavelength of light (color) is not the same as measuring physical parameters such as pressure or adhesion because color is not a physical object. Color is a visual complication and part of the visualization process. The wavelength of light, which is also representative of color is required to be known in many applications, it can be measured in two general ways: direct and comparative. In the direct method, the wavelength is measured by one of the interferometric techniques. In these methods, by creating two different paths originated from a light source, its wavelength is measured knowing the physical path difference.In the comparative method, a reference is used to measure the wavelength. This reference can be a light source with a fixed and known wavelength, optical materials (filters with one of the fixed and definite properties), wavelength-sensitive geometric shapes (prism or optical grating). A spectrometer is a tool used to observe and analyze the radiation or absorption spectra of materials. A widely used type of spectrometer is sampleless spectroscopy. This means that the light input signal is unknown and the purpose of spectroscopy is to determine the wavelength of this unknown signal. These spectrometers have a wide range and high spectral resolution, but they are expensive and bulky. In the last decade, microwave signal processing by optical method has been considered due to its high bandwidth, low losses and immunity to electromagnetic interference (EMI). Conventional electronic methods for measuring microwave frequency are thought to be limited by the limitations of electronic systems. These limitations include low speed, bandwidth, and vulnerability to electromagnetic interference. Microwave frequency measurement based on optical methods are potential alternatives in this field. The basic idea for this research has been adopted from Instantaneous frequency measurement (IFM) technique.

2.Instantaneous frequency measurement

Instantaneous frequency measurement is important for receivers of new warning radars. [1] Older IFM receivers are built using interferometers. These interferometers are implemented using hybrid couplers and delay lines. The bandwidth of such a design can be limited due to unwanted radiation and other limitations of radio frequency devices; therefore, optical methods have been proposed as a tool to increase the bandwidth and speed of signal processing systems. A method is based on the production of a two-frequency laser by the Mach-Zander modulator in which measurement error is improved due to the temperature instability of Bragg gratin [3]. Morozov and Lavanov reported a more accurate work in 2017 using an amplitude-phase modulation technique[4]. Emami et al studied Measurement of the frequency of the microwave signal using the Hilbert converter and its practical construction[5]. Drummond et al performed IFM using interferometry. Frequency measurement is independent of the input signal strength [6]. In another method, a phase modulator and a laser source are used. The microwave signal is first modulated and then divided into two optical paths[7].Another method for measuring instantaneous microwave frequency with higher resolution is the optical power measurement method, which uses an FBG. In addition, the resolution of the measurement obtained due to the use of an FBG is much higher than the previous method. The system structure is shown in Figure 1. The microwave signal is applied through the RF port in MZM. The modulated optical signal is sent to the FBG via an optical circulator. The LD wavelength is equal to the central FBG wavelength [2]. The transmitted and reflected signals are read by two low frequency sensor. RF frequency can be estimated based on the power ratio value.

In this work, the above ideas are used to directly measure the wavelength of unknown received light. The structure of the proposed system as shown in Figure 2 is achieved by replacing the optical circulator with a beam splitter and the FBG with a ND filter in figure 1. The transmission diagram of ND filter is shown in Figure 3. To a good approximation the transfer characteristic is linear in the wavelength range of 750 to 950 nm.

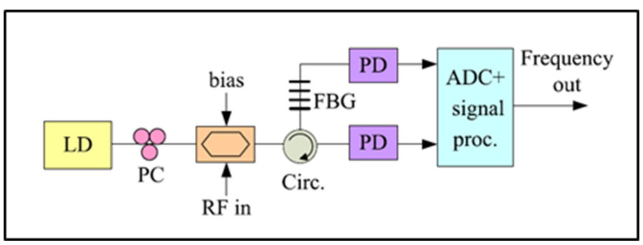

Figure 1. Wavelength measurement system using FBG [2]

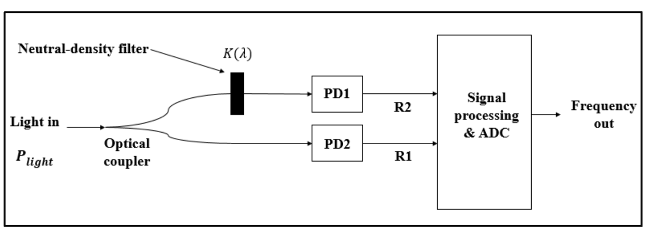

Figure 2. Visible light Instantaneous wavelength measurement structure

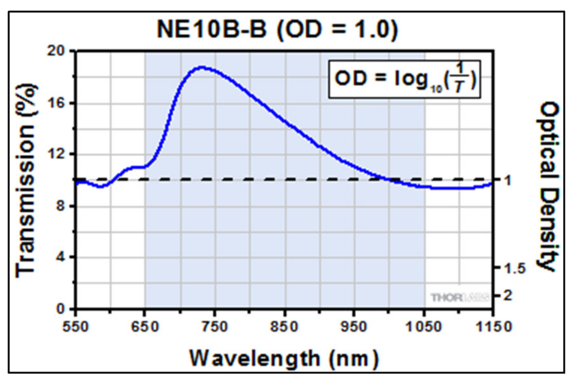

Figure 3. Transmission of Neutral-density filter[8]

In this plan; the light under study as the input, is directed to two separate paths using optical coupler. These two light beams, which are exactly the same, enter the two silicon diode detectors and are converted to the same voltage through two similar amplifiers. The slightest difference in the characteristics of the components or in the path of light transmission will cause a difference in the outputs. The result of comparison of the outputs in the same condition will be one. Placing an optical filter in one of the branches of the optical path will attenuate the optical signal resulting a decrease in voltage output. The mathematical analysis of the circuit with the help of simple conversion functions is discussed below. Assuming the light transmittance K (λ) for the filter (almost a linear coefficient that is a function of wavelength) and also considering P for the sensitivity(responsivity) of the sensors , the output of the sensors 1 and 2 is calculated as follows:

$$R_2 = P_2 \times P_{light} \times K(\lambda), R_1 = P_1 \times P_{light} \quad (1)$$

Where P_{light} is the input light power. R2 is the sensor output in the filter path. We have two values divided by:

$$\frac{R_2}{R_1} = \frac{P_2 \times P_{light} \times K(\lambda)}{P_1 \times P_{light}} \quad (2)$$

Given that both sensors are selected from the same type and operate at the same temperature, P_1 and P_2 (sensor sensitivity) can be considered equal. Therefore, the result of the division is equal to K(λ).

From the above, it can be concluded that the output of the system will be only a function of K(λ). Four LEDs with a power of 3 watts and at wavelengths of 750, 805, 850, 950 nm were used as light sources. The experiment was performed by controlling the intensity of light.The test results are shown in Table 1. For each wavelength, 5 test steps were performed to completely cover the dynamic range(0-5V). As the light intensity of the sources changes, the output of the photodiodes is measured .The result of dividing each step of the experiment is also calculated. The result of dividing all the steps in the whole dynamic range has no overlap. It can be concluded that these 4 wavelengths are separable. The processor maps the result of each division to the corresponding wavelength and displays it. The diagram of the unfiltered photodiode output in terms of the output of the filtered photodiode is drawn in Figure 4. It can be concluded that the system is linear in the dynamic range.

In this paper, a method for instantaneous measuring the wavelength of the visible and infrared light is presented. In the research background, various spectroscopic methods were explained. Because electronic methods have limited bandwidth and speed. Then a new method for spectroscopy in the range of 750 to 950 nm of visible light using this methods was presented.

LED Wavelength	Filtered photodiode output (mv)	Unfiltered photodiode output (mv)	division result
750nm	81	550	0.147273
	194	1300	0.149231
	341	2282	0.14943
	458	3100	0.147742
	600	4100	0.146341
805 nm	80	551	0.145191
	182	1279	0.142299
	344	2381	0.144477
	419	2901	0.144433
	580	4080	0.142157
850nm	59	470	0.125532
	170	1332	0.127628
	281	2240	0.125446
	414	3270	0.126606
	557	4401	0.126562
950nm	48	469	0.102345
	144	1400	0.102857
	230	2232	0.103047
	344	3321	0.103583
	408	4079	0.100025

Table 1. Output voltages of PDs.

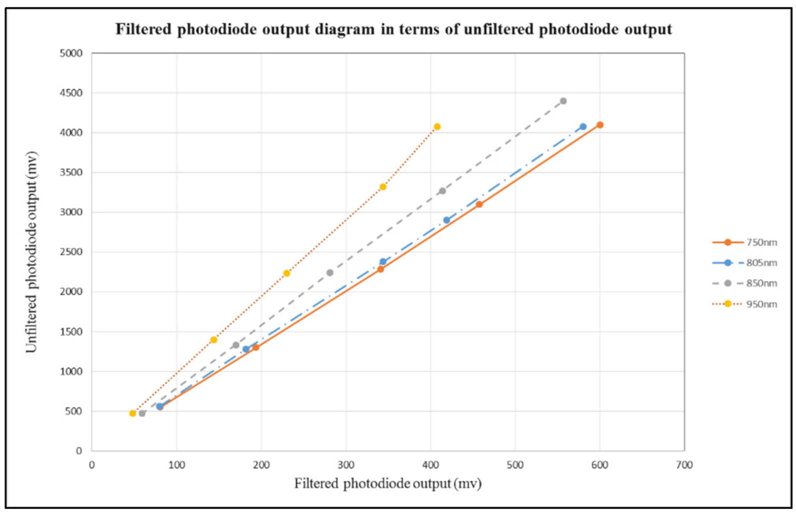

Figure 4. Filtered photodiode output diagram in terms of unfiltered photodiode output

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