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Optical frequency drift measurement using a birefringent medium and a polarimeter

T. Mengual, B. Vidal and J. Martí

Abstract: A simple technique to measure the frequency drift of monochromatic optical sources based on the polarization change caused by a birefringent material is demonstrated. Preliminary experimental results show a resolution of 0.8 pm.

Indexing terms: Lightwave analyzers, Birefringence, optical fibre polarisation, optical instruments

***Introduction*:** Several approaches [1-3] have been proposed to accurately measure the wavelength of a monochromatic light, for example using optical bandpass filters, grating spectrometers or interferometric techniques, to cite a few examples. However, these methods usually are based on complex, specific and expensive devices. In [2] a technique to determine the wavelength of a monochromatic light based on the power ratio between the orthogonal polarization components at the output of a birefringent material was proposed. Nevertheless, this technique shows limited resolution due to the need of two photodiodes.

In this paper, a wavelength meter based on off-the-shelf devices (a differential group delay module and a polarimeter) is proposed and demonstrated. The setup shows improved resolution over previous proposals [2]. Changes in the wavelength of the optical carrier can be derived from the Stokes parameters. The technique is similar to the Poincaré Arc Method used to determine the DGD of a test device as wavelength is changed but, unlike it, the aim is the accurate measurement of the wavelength shift.

Principle of operation: At the output of a birefringent material, such as a differential group delay module, exists a pair of principle states of polarization that describe a sphere diameter about which the output polarization rotates when wavelength is changed [4]. If the differential group delay (DGD) of the birefringent medium is known, it is possible to determine the frequency shift from the change in the Stokes parameters of the polarization output as given by [1]:

$$\Delta\omega = \frac{\Delta\theta}{DGD}, \qquad (1)$$

where $\Delta\omega$ is the incremental change in radian optical frequency and $\Delta\theta$ is the radian angle of the arc. Thus, frequency drifts can be measured from the angle of the arc described by the Stokes parameters around the principal state of polarization.

The wavelength meter diagram is depicted in Figure 1. The optical signal is launched through a linear polarizer to the birefringent medium (DGD). To increase frequency resolution the polarizer has to be at an angle of 45° to the DGD axis. In addition, the polarizer avoids frequency errors caused by changes on the optical signal polarization. At the output of the DGD, a standard polarization analyser measure the polarization state (i.e. Stokes parameters).

At the output of the DGD the signal polarization rotates when optical frequency changes describing a circumference on the Poincaré sphere. To determine $\Delta\theta$, the centre of the circumference has to be obtained. It can be done changing the frequency of the source and measuring three points on the Stokes space. The centre of the circumference is the centre of the Poincaré sphere if the optical signal is launched at 45° to the DGD axis and therefore the radius of the circumference is maximum. Once the centre of the circumference has been obtained, changes of the signal frequency can be measured in a certain range from $\Delta\theta$, as shown in Figure 2.

The range wherein a frequency drift can be unambiguously determined is $\Delta\omega=2\pi/DGD$, i.e. the smaller the DGD the larger the frequency range. On the other side, a larger DGD means a better resolution. Therefore, there is a trade-off between resolution and frequency range.

If combined with a reference source of known frequency, absolute frequency measurements instead of relative ones could be done using this technique.

***Experimental results*:** Figure 3 shows the block diagram of the experimental setup used to carry out preliminary experiments. To show the feasibility of the technique, the frequency drift of a DFB laser was measured using the proposed technique and a commercial wavelength meter with a resolution of around 0.04 GHz.

To measure a frequency drift by means of the Stokes parameters, a monochromatic optical source is launched to the DGD module. The DGD was measured using the fixed-analyzer method to be 62.3±0.4 ps. Then, the signal is split in two branches to measure the frequency simultaneously using a polarimeter and the wavelength meter.

Since in our setup the axis of the polarizer cannot be adjusted, a polarization controller is used to ensure that the light does not impinge on one of the DGD axis, otherwise a change in the wavelength would not lead to different states of polarizations at the DGD output. This polarization controller is not necessary if the polarizer can be placed just before the birefringent crystal with the proper angle (Figure 1), for example, by the use of a DGD module incorporating a polarizer.

Using the setup of Figure 3, two kinds of measurements of the wavelength change were carried out corresponding to the proposed technique and the commercial wavelength meter. Two set of measurements were carried out changing the laser wavelength. Next in order to compare both sets of measurements, a linear fit was done. As can be seen in Figure 4, the correlation coefficient (R = 0.998) indicates that our results agree quite well with the measurements obtained using the commercial wavelength meter. Finally, to demonstrate the technique capability to measure the frequency drift of a monochromatic signal, the time evolution of the laser wavelength was measured when it was switched on. As can be seen in Figure 5, the measurements provided by the technique are within the rage of the wavelength meter precision.

The maximum frequency error was theoretically estimated for our setup to be 0.1 GHz (0.8 pm) and was mainly limited by the measurement accuracy of the DGD value. The inset of Figure 5 shows the absolute difference between the experimental results provided by the polarimeter and the wavelength meter which are much better than 0.1 GHz (maximum difference: 50 MHz). Accuracy can be increased by a better characterization of the DGD value as well as the usage of a larger DGD.

***Conclusions*:** In this Letter, a technique to measure the frequency drift of a monochromatic signal from the evolution of the Stokes parameters at the output of a birefringent medium has been demonstrated. The technique allows the accurate measurement of frequency drift (for instance to study the long-term stability of optical sources) and it is based on a birefringent medium and a polarization analyser (off-the-self components) therefore avoiding the need of complex devices such as interferometers or grating-based spectrometers. Moreover, absolute frequency measurements could be done using this technique combined with a reference source of known frequency.

On the other side, there is a relation between the DGD and the resolution of the technique which can be improved using larger DGD values, showing potential for further improvements.

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Figure captions:

Fig. 1 Schematic diagram of the wavelength meter

Fig. 2 Arc described by an optical signal on the Poincaré sphere when its frequency is changed

Fig. 3 Experimental setup to proof the concept

Fig. 4 Comparison of the frequency change measurements done with the polarimeter and a commercial wavelength meter

Fig. 5 Frequency drift measurements carried out with the proposed technique (circle) and a wavelength meter (box). Inset: absolute difference between the experimental results provided by both procedures

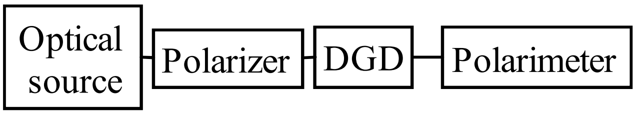

Figure 1

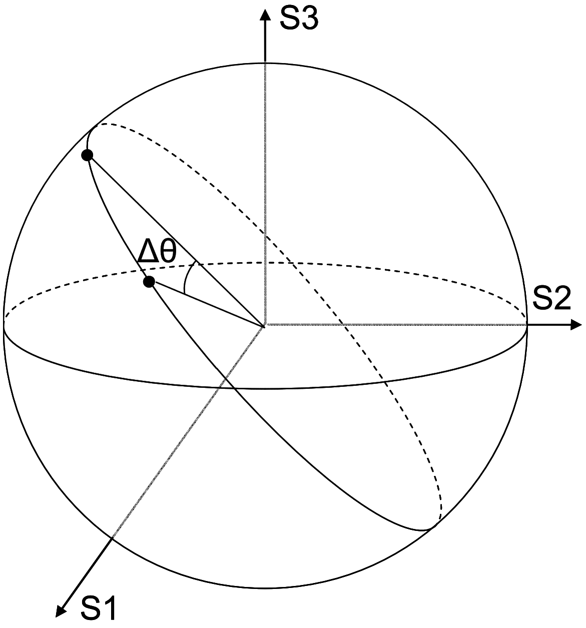

Figure 2

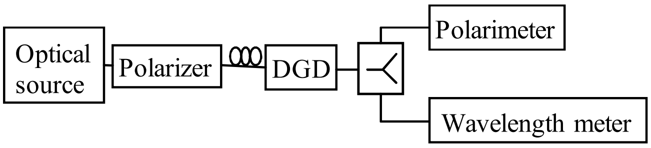
Optical source
Polarizer
DGD
Polarimeter
Wavelength meter

Figure 3

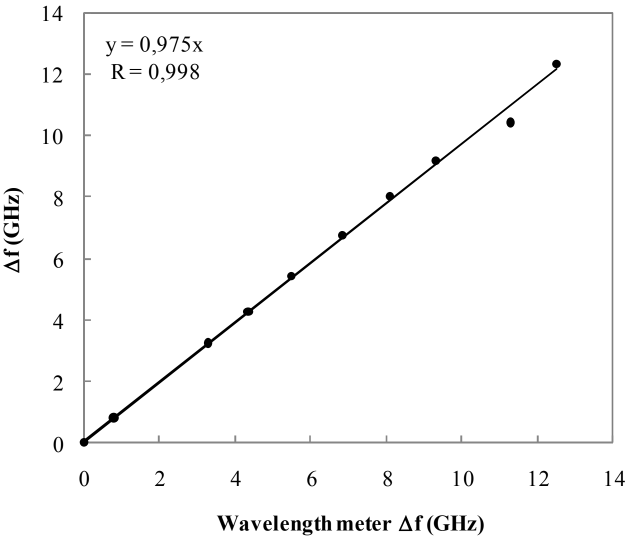
y = 0,975x
R = 0,998
Δf (GHz)
Wavelength meter Δf (GHz)
0
2
4
6
8
10
12
14
0
2
4
6
8
10
12
14

Figure 4

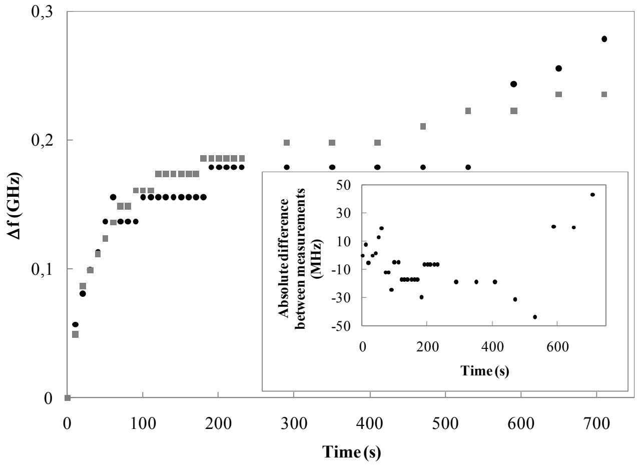
0,3
0,2
0,1
0
Δf (GHz)
0
100
200
300
400
500
600
700
Time (s)
50
30
10
-10
-30
-50
Absolute difference between measurements (MHz)
0
200
400
600
Time (s)

Figure 5