Measurement of frequency swept linearly with Fabry-Perot fiber inetrefrometer

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Abstract

Synthetic aperture imaging ladar (SAIL) used a series of pulses in which the optical frequency was swept linearly in time over a bandwidth greater than several gigahertz. The linearity of such broadly tunable sources is often poor which is leading to phase errors. Many methods are adopted to correct for quadratic and higher-order phase errors such as the reference channel or algorithm for unmatched channel of Aerospace and the reference interferometer of Naval Research Laboratory. If the real value of frequency swept quasi-linearly is measured another direct way to mitigate the waveform linearity problem can be developed. At first the frequency curve is measured with Fabry Perot fiber interferometer. Experiment and results are explained in detail in this paper. The quadratic and higher-order terms of frequency swept are calculated. They may be used to deduce the phase errors directly later. At the same time the wavefront is also measured by a Jamin shearing interferometer through the fringe analysis.

Keywords: sweep frequency, linearity, Fabry-perot etalon, quadratic order, measurement

1 INTRODUCTION

Chirped lasers are finding uses in many applications including coherent laser ranging and synthetic aperture imaging ladar(SAIL). The measurement and characterization of the wavefront and the frequency of a laser is a necessary step for successful applications of chirped laser sources.

The wavefront of chirped laser is characterized with short coherent length comparing with unchirped laser. The measuring methods include microlens array and interferometers with equal interference length. In this paper we use a Jamin shearing interferometer that utilizes interference fringes to evaluate wavefront and sweep rate.

The Fabry-Perot interferometer presented by Repasky et al. [1] is used for measurement of the frequency-chirped response of the laser. The deviation from a Lorentzian line shape of a flat-plate Fabry-Perot is proportional to the frequency of chirped laser. The free spectral range (FSR) of Fabry-Perot interferometer is 22.4GHz.

The simple method of sweep rate and tuning range measurement is presented by Kazharsky et al.[2] This method uses a Fabry-Perot etalon with FSR of about 6GHz. As the laser is tuned through the resonant condition of the etalon, the transmitted power goes through a maximum. The sweep rate and tuning range is deduced from the number of transmitted maximum and time. The method requires decreasing FSR to give more information.

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In this paper we use a simple Fabry-Perot etalon of fiber to measure the sweep rate. The decreased FSR of Fabry-Perot etalon improved the sampling sensitivity. The first-order and second-order fitting curves of frequency are deduced with slight residuals. That can be of interest for correcting quadratic and higher-order phase errors of SAIL.

2. THEORY

2.1 JAMIN INTERFEROMETER MEASUREMENT

The Jamin lateral shearing interferometer is adopted to evaluate laser wavefront and sweep rate. It includes two equally thick plane-parallel glass plates of the same refractive index, in which two plates of the same size are inserted for shearing. There is equal optical path interfered between two beams. The wavefront can be deduced from the fringes. There are many methods explained in detail [3]. Here is omitted.

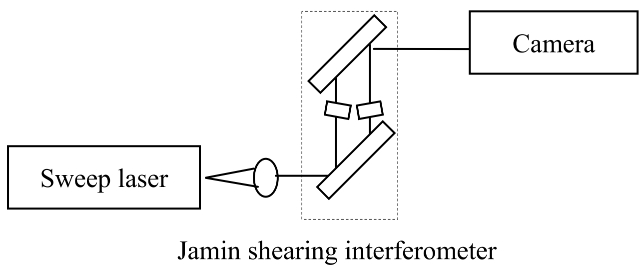

Figure 1. Schematic of the Jamin interferometer measurement

The sweep rate can be calculated from the change of the fringes. For perfect spherical wavefront the wavefront function can be written:

$$W(x,y) = \frac{x^2 + y^2}{R^2} W_m \tag{1}$$

where W_m is wavefront aberration at the edge of the exit pupil, R is radius of the exit pupil.

Hence the deviation between shifted wave fronts is:

$$\Delta W = W(x + \tfrac{S}{2}, y) - W(x - \tfrac{S}{2}, y) = \frac{2Sx}{R^2} W_m \tag{2}$$

where S is the amount of shear between the shifted wavefronts on the interferogram screen. The fringe equation is below, where d is the difference adjusted between two coherent beams, P is the fringe order which is P0 when x=0.

$$W_m \frac{2Sx}{R^2} = P\lambda + d \tag{3}$$

Correspondingly, their fringe spacing is given by T.

$$W_m \frac{2S}{R^2} = \frac{\lambda}{T} \tag{4}$$

Equation (3) is deviated by the time t, then substituting equation (4) in it. The movement of the fringe v is proportional to the frequency-sweep rate, the differentiation of f (t).

$$v = -\frac{dT}{\lambda^2}\lambda'(t) = dTf'(t) \tag{5}$$

The distance d and the fringe spacing T are amplified factor to the sweep rate. It is interesting that the movement of the fringes also can be used for equal optical path adjustment used by white light interferometer. When the movement of the sweep laser fringes is minimum the distance d approaches to zero.

2.2 FABRY-PEROT ETALON MEASUREMENT

Sweep linearity can be measured by measuring the transmission through an etalon [4]. An effective and simple etalon is a non-angled short length of fiber coated with high reflectivity. As the laser wavelength is swept the transmission through the etalon as a function of wavelength can be expressed as:

$$\frac{I_t}{I_i} = \frac{(1-R)^2}{(1-R)^2 + 4R\sin^2(\delta/2)} \tag{6}$$

When there is normal incidence on the fiber facet,

$$\delta = \frac{4\pi nl}{\lambda} \tag{7}$$

R is the reflectivity of the end surfaces, n is the index of refraction, *l* is the length of the fiber and λ is the wavelength.

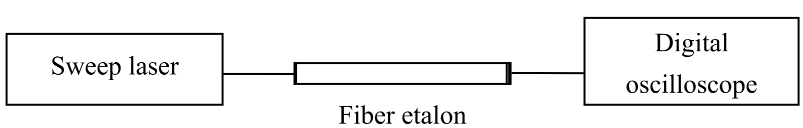

Figure 2. Schematic of Fabry-Perot etalon measurement

3 EXPERIMENT AND RESULT

Figure 1 is a schematic of the experimental setup used to demonstrate the measurement of a chirped frequency response with Jamin interferometer.

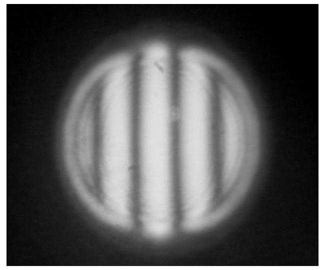

Figure 3. The shearing fringes of the chirped laser

The collimated output of a chirped laser is New Focus Tunable laser with the tuning range of 1520-1630 nm. The collimated lens diameter is 10mm measured by the interferometer. Figure 3 shows the shearing fringes of the chirped laser. The high speed sample data are used for evaluating the chirp speed coarsely.

Figure 2 shows the setup of the Fabry-Perot etalon measurement. The 0.2m and 0.5m fibers are adopted with the FSR of 500MHz and 200MHz respectively. We choose the experimental tuning range of laser with 1nm from 1550 nm to 1551 nm and the speed with 1000nm/s or 2000nm/s according to the sensibility of FP etalon and the memory depth of oscilloscope. The reflectivity of fiber front and back facets is 0.9 that the finesse of FP is 300. The sample speed of the oscilloscope is 12.5MHz or 25MHz. Every pulse includes about 20 sample points.

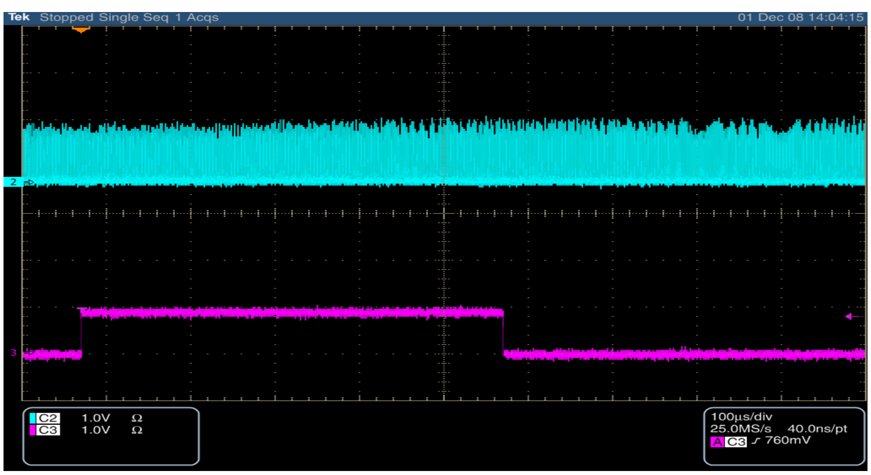

Figure 4. The sample display of the oscilloscope

Figure 4 is the display of the oscilloscope in which there is the transmission of FP (up) and the trigger signal of the tuning laser (down). The sample speed is 25MHz.

Figure 5 shows how the transmission varies as a function of wavelength for a fiber of length 0.5m. The transmission is at a maximum whenever $2nl/\lambda$ is an integer.

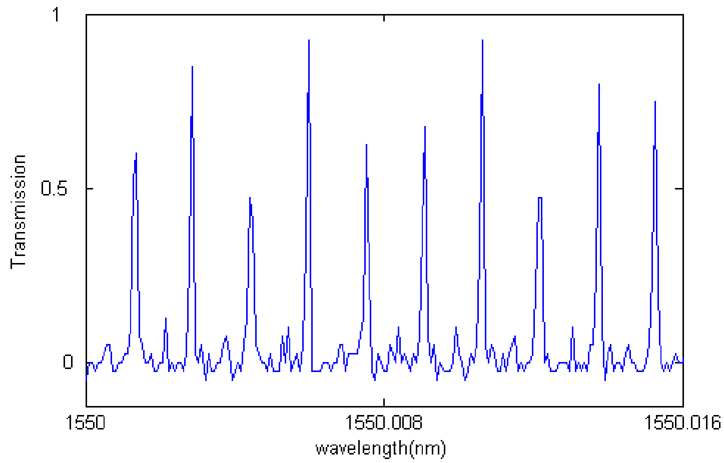

Figure 5. The experimental transmission (the beginning part as example) for the fiber of 0.5m

Thus by detecting the peak and measuring the time interval between peaks, we can determine the average speed from peak to peak. The peaks in name of the frequency are lineally fitted as the function of time. Figures 6-8 show the fitting results and residuals of different tuning speed, fiber length and fitted order.

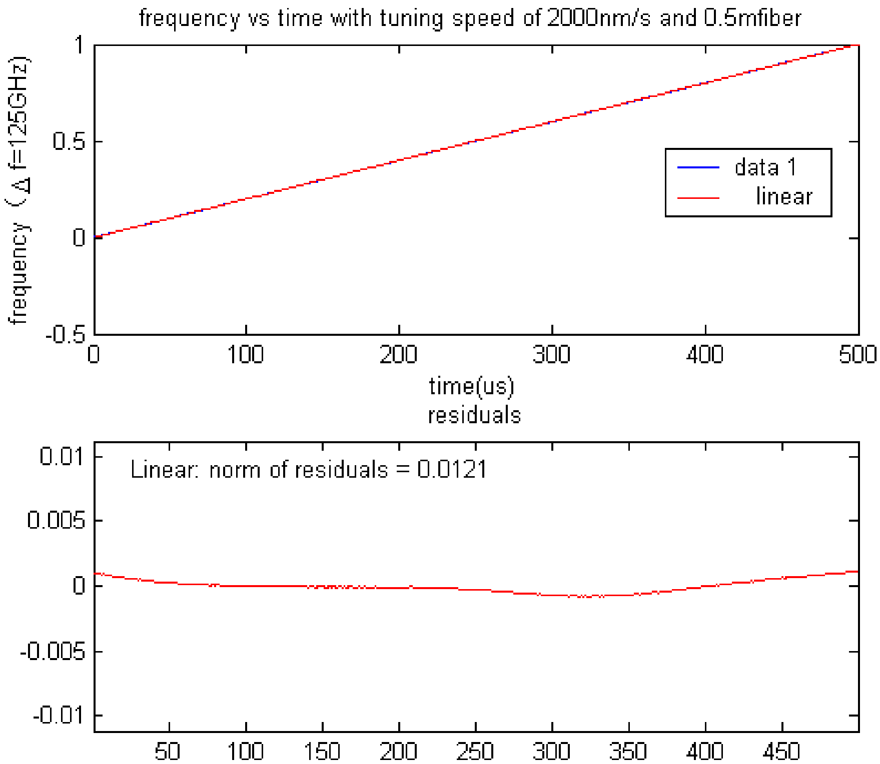

Figure 6. The first-order fitting line and residuals of the frequency with the 0.5m fiber and 2000nm/s tuning speed. The frequency unit is 125GHz which is correspond to the wavelength range of 1nm.

The residuals are obviously decreasing when the second-order fitting replaces the first-order. The residuals of the third-order fitting are almost the same level as them of the second-order. The second-order fitting equations of frequency and wavelength are shown below with 1000nm/s tuning speed. The corresponding first-order and second-order phase can be deduced form the equation (8) and (9). It is useful for decreasing the phase error of SAIL.

$$f(t) = f(0) - 1.25 \times 10^{14} t + 1.16 \times 10^{14} t^2 \tag{8}$$

$$\lambda(t) = \lambda(0) + 1.000 \times 10^{-6} t + 3.64 \times 10^{-7} t^2 \tag{9}$$

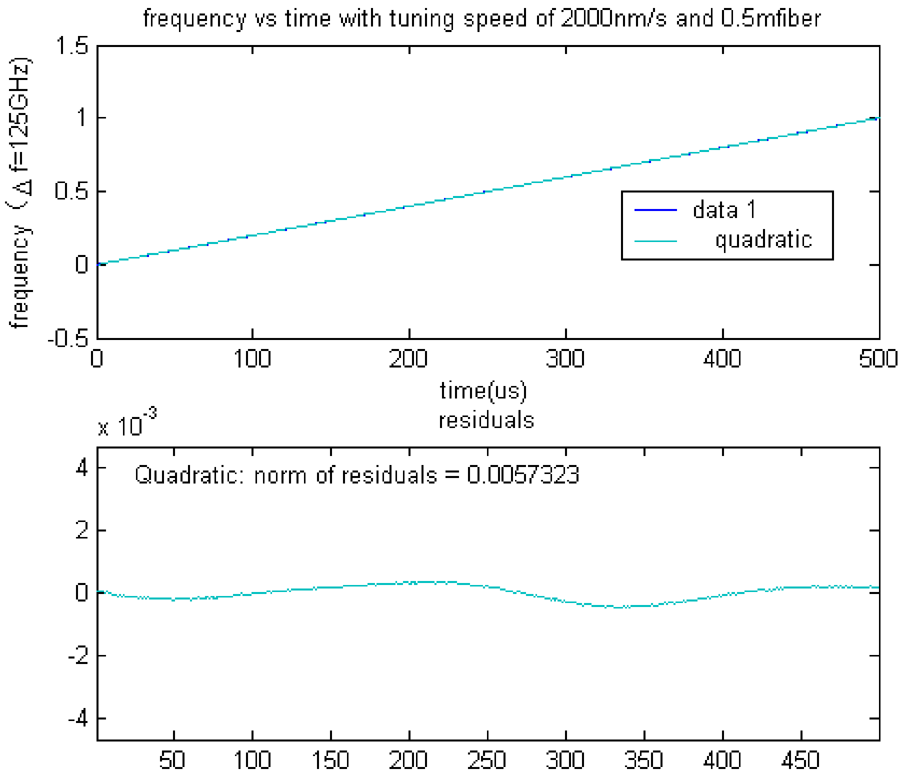

Figure 7. The second-order fitting line and residuals of the frequency with the 0.5m fiber and 2000nm/s tuning speed. The frequency unit is 125GHz which is correspond to the wavelength range of 1nm.

4 CONCLUSIONS

A Jamin shearing interferometer and A simple Fabry-Perot etalon are used for measurement and characterization of the wavefront and the frequency of a chirped laser usually used for SAIL etc. The experiment and the results have been presented. The frequency fitting results may be applied to decrease the phase error of SAIL in next step. The authors thank the support of CAS.

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