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Laser interference signal acquisition for Fourier transform spectrometer

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ABSTRACT

The laser interference signal provides effective control signal for the reliable operation of atmospheric sounder. Main components of interferometer are presented by analyzing the principle of swinging interferometer in this paper. In order to acquire the laser interference signal, it is necessary to design a method of signal acquisition for the interferometer with analyzing the noise performance of the preamplifier. By means of an interference experiment of He–Ne laser, the sinusoidal signal is obtained, the frequency of which varies with change of angular velocity of moving mirrors. The experimental results indicate that the principle of swing interferometer is feasible, and that the method of interference signal acquisition is correct.

1. Introduction

The atmospheric sounder is a high resolution spectrometer based on the Fourier transform. Through the space remote sensing, the atmospheric sounder can obtain high spectral resolution and multi-channel infrared radiation spectrum from the atmosphere and the earth surface. After inversion, it is to get highly precise atmospheric parameters on temperature and humidity of the vertical distribution [1,2]. During the process of atmospheric sounder's moving mirror uniform motion, the reference interferometer of the atmospheric sounder, can use the wavelength of He–Ne laser source of 632.8 nm, and then be simultaneously modulated with the target infrared radiation in the main interference system. To acquire control signals, processing of the laser interference signal received by the silicon photoelectric detector is called for, so that the optical path difference interval sampling in the main interferometer can be triggered and the mirror uniform motion can be controlled.

This paper introduces the principle of the swing interferometer and main components of the interferometer, and then further proposes a method of signal acquisition of the interferometer. By designing a photoelectric detection circuit with low noise based on JFET operational amplifier LF357, we can extract signals buried in noises. The data acquisition unit then can enable us to acquire the laser interference signal, and get corresponding experimental results. In this way, the acquisition of sinusoidal interference signals can provide effective control signals for the reliable operation of the atmospheric sounder.

2. Description of the swing interferometer

2.1. The principle of the interferometer

There are many types of Fourier transform spectrometer, but commonly used ones include the Michelson interferometer, the Sagnac interferometer and the birefringent interferometer [3,4]. In the swing interferometer, a beam of light into the interference mechanism with an incident angle α. Through the reflection and transmission of the beam splitter, this light becomes two beams of light, which can then go through the back and forth reflections from fixed mirrors and moving mirrors. Interference is formed because of respective transmission of the two coherent beams of light by the light beam splitter. Thus, the two coherent beams of light have caused interference on the other side of the beam splitter. After this interference is received by the photoelectric detector, the interferogram is formed. Fig. 1 illustrates the light path diagram within the framework of the swing interferometer.

On the swinging platform, there are three pieces of moving mirrors, which are symmetrical, relatively fixed and moving at the same time. Hence, we can reduce the error influence caused by moving mirrors' inclination as well as the impact of structure vibration on the interference performance, thereby improving the structure stability and environmental adaptability of the interferometer [5,6].

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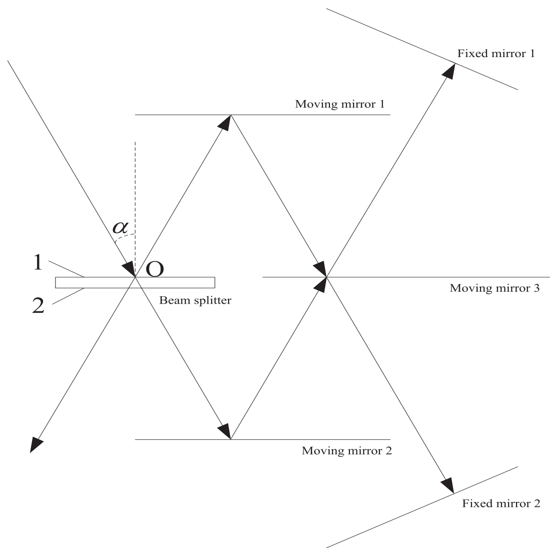

Fig. 1. The principle of the swing interference.

Table 1
He–Ne laser parameters.

Wavelength (nm)	Power (mW)	Beam diameter (mm)
632.8	2	0.7
Divergence angle (mrad)	Power stability	Output mode
1.4	±1%	TEM_{00}

2.2. Main components of the interferometer

Major interference system components of the interferometer include plane mirrors, a laser, a photoelectric detector and a beam splitter. The analysis of interference signal modulation efficiency indicates that, in order to realize the interference modulation efficiency $M \geq 0.9$, the maximum value of the curve error of mirror ζ should be $\zeta_{max} \leq \lambda/8$. If the PV value of the mirror is set at $\lambda/8$, the RMS value should be $\lambda/30$. Taking the performances of material processing and reflective surface manufacturing into consideration, we choose K9 glass for the plane mirror body material, and film and protective film for the mirror [7,8].

Lasers can be subcategorized into gas lasers, semiconductor lasers and solid lasers. The He–Ne laser, one of the most widely used gas lasers, has its advantages and disadvantages. The advantages include good frequency stability as high as 10^{-7}, which means that the output beam is in a circularly symmetric distribution in the single mode output. The disadvantages are its vulnerability to environmental factors like the temperature and the current, its demand for high voltage power supply and a sealed container, its large size, and its high power consumption. The He–Ne laser is an ideal light source for laser interference experiments, and related He–Ne laser performance parameters are shown in Table 1.

The light source of the laser interferometer is the He–Ne laser with the wavelength of 632.8 nm. Therefore, the silicon photoelectric detector is used to detect laser interference signals, and the detection unit is Φ 3 mm. The spectral response of the silicon photoelectric detector ranges from the visible light to the 1100 nm, covering the He–Ne laser wavelength. The response time is between 10^{-9} to 10^{-8} s. Besides, this process is also characterized by its fast response speed, the low dark current and the high response rate.

In the interferometer, the beam emitted by the He–Ne laser, through the beam spread collimation by a 10-time-magnification laser beam expander, is converted into the polarized parallel beam, whose diameter is 7 mm. Being launched into the center beam splitter with 30° incident angle, this parallel beam is reflected and transmitted by the beam splitter. Thus this parallel beam is divided into two, which are launched respectively into the symmetric moving mirrors. The divided two beams then return along the same route after the back and forth reflection between the fixed mirrors and the moving mirrors. Interference is formed when these two just-returned beams are combined by the beam splitter.

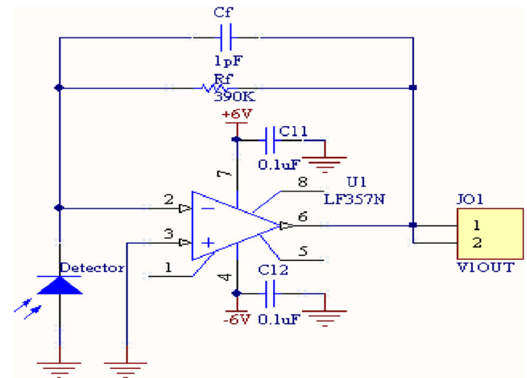

Fig. 2. The preamplifier circuit.

3. Acquisition method of the interference signal

3.1. Low noise analysis of the preamplifier

The laser interference signal is weak current signal at the μA level. In order to obtain such weak signal, it is necessary to design a photoelectric detection circuit with low noise. Based on the interference signal's generation principle in the swing interferometer, we can get the modulation frequency f of the laser interference signal:

$$f = \frac{C\omega}{\lambda} \tag{1}$$

where the interferometer constant is $C = 8k\sin\alpha = 0.4$ m, the angular speed of moving mirrors' uniform motion is $\omega = 0.533$ rad/s, and the He–Ne laser wavelength is $\lambda = 632.8$ nm. Then we get $f = 337$ kHz, on the basis of which other relevant circuit parameters can be found out.

In the photovoltaic mode, the silicon photoelectric detector can achieve very accurate linearity, and make the amplified signal proportional only to the incident light intensity. If the dark current is zero, the detector noise is mainly the thermal noise and shot noise. When the signal to be measured is the weak current signal at the μA level, it will be helpful to improve the signal-to-noise ratio of the system [9]. Fig. 2 presents the preamplifier circuit of the photoelectric conversion.

If the preamplifier circuit wants to convert μA photocurrent signal into a voltage signal mapping with the subsequent circuit, then the amplifier should be highly resistant and of low noise [10]. Based on the circuit noise theory, the noise coefficient of the cascade network of the photoelectric detection circuit is mainly affected by the preamplifier noise coefficient. Attention must be paid to several factors, namely the shot noise and thermal noise of the silicon photoelectric detector, the voltage noise and current noise of the preamplifier circuit, and the thermal noise of the feedback resistor. Then we can get the noise voltage output of the preamplifier circuit within the system bandwidth:

$$V_n = \sqrt{(V_{nt}^2 + V_{ns}^2 + V_{ne}^2 + V_{ni}^2 + V_{nr}^2) f_{3\ \mathrm{dB}}} \tag{2}$$