Fiber Noise Suppression System with Additional Linewidth of mHz-Level for Ultra-Stable Lasers

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***Abstract*—We demonstrate a fiber noise suppression system used in the ultra-stable laser aiming to compress the laser linewidth in remote place. This system is realized by using an active feedback control technique and composed of a Michelson interferometer and phase locked loop. This paper reported the fiber noise suppression system can reduce the extra linewidth introduced by the 1 m long fiber from the initial 250 Hz to 1.8 mHz.**

Keywords—ultra-stable laser; fiber noise; noise suppression; phase locked loop

I. Introduction

Continuous wave lasers with ultrahigh frequency stability play key roles in many fields, such as optical atomic frequency standard [1], ultra-low phase noise photonic microwave generation [2,3], gravitational wave detection [4], fundamental physics tests [5], and ultrahigh resolution very-long-baseline-interferometer [6]. The 1550 nm wavelength ultra-stable laser at the transmission window of fiber communication realizes long distance laser signal transfer over fiber links. However, the noise introduced by the transmission fiber will deteriorate the linewidth and frequency stability of the ultra-stable laser. Therefore, the fiber noise suppression method is one solution for maintaining the excellent linewidth and high frequency stability of the ultra-stable laser.

II. Experimental Setup

To suppress the noise introduced by the environment where the ultra-stable laser output fiber is located, active feedback control is applied in the fiber noise suppression system [7]. A schematic diagram of this approach is shown in Fig. 1. The frequency-stabilized ultra-stable laser is separated into two parts with unequal power after passing through polarizing beam splitter (PBS), by tuning the half-wave plate, and a small part is used as the reference light. The large part is modulated by the AOM, with a resonance frequency of 110 MHz, after which it is coupled into the single-mode fiber through an angled physical contact (PC) interface. The fiber output end uses a PC interface, which can reflect 4% of the light to the original optical path according to Fresnel's law. The noise introduced by this transmission fiber can be analyzed by detecting the beat note of the reflected light and the previous small part of the reference light in the PBS. Thereafter, the noise can be suppressed by tuning the VCO's voltage of the AOM driver, which is frequency-stabilized onto an RF reference via a loop filter. The loop filter employs a PI (proportional-integral) algorithm, and is shown in the blue block of Fig. 1. Note that the reflected light passes through the transmission fiber and AOM twice. Therefore, the error signal must be twice the frequency of the frequency divider in the fiber noise suppression system.

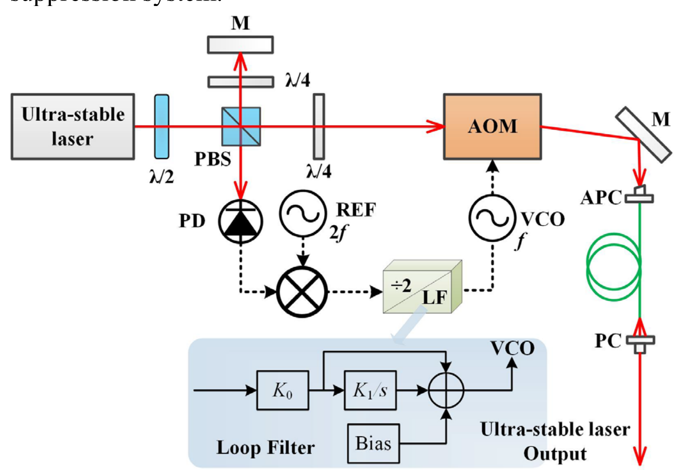

Fig. 1. Experimental setup of the fiber noise suppression system. λ/2: half-wave plate; λ/4: quarter-wave plate; AOM: acousto-optic modulator; APC: angled physical contact; PC: physical contact; PD: photodetector; M: mirror.

To evaluate the performance of this fiber noise suppression technology, we have measured the additional linewidth of beat note between the optical fiber output light and the reference light. The reference light has not passing through the AOM. A 1-meter long single mode fiber is used for the transmission fiber, then we tested the additional linewidth separately with and without using the fiber noise suppression technique.

Fig. 2 shows the linewidth compression results of fiber noise suppression system for the noise introduced by the transmission fiber when the ultra-stable laser is transmitted in a 1 m long fiber. The left part of Fig. 2 is the additional linewidth introduced by transmission fiber of about 250 Hz without noise suppression transmission. And the right part of Fig. 2 is the additional linewidth of 1.8 mHz after fiber noise suppression system. This result shows that the fiber noise suppression technique can effectively suppress the noise introduced by the transmission fiber. And Such optical fiber noise suppression method does not require remote to build optical return path, only needs to use FC / PC connector. This method effectively improves the application range of fiber optic transmission systems.

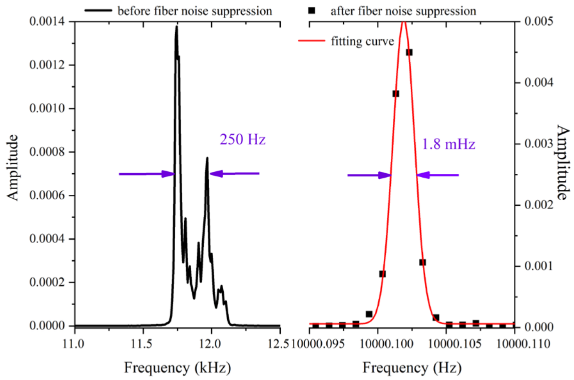

Fig. 2. The additional linewidth introduced by transmission fiber before and after optical fiber noise suppression system.

III. Conclusions

We have reported a fiber noise suppression system for ultra-stable laser transmission in optical fiber link, which are used a Michelson interferometer and phase locked loop. Preliminary experiments show that the optical fiber noise suppression system in the 1 m long fiber can reduce the extra linewidth introduced by the fiber from the initial 250 Hz to 1.8 mHz. Thanks to the fact that there is no need to build additional optical paths at the remote end of the fiber noise suppression technique, this method is conducive to the application of optical fiber transmission systems.

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