Optical frequency measurement comparison using fiber laser combs between NIMT and CMS

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Abstract. A NIMT optical frequency comb was compared with an Er-fiber laser comb with repetition frequency of 250 MHz made by the Center for Measurement Standards (CMS), Taiwan, by simultaneously measuring the frequency of a 633 nm He-Ne laser. The difference of average frequency measurement is 283 Hz and corresponds to a relative difference of 6.0x10^-13.

1. Introduction

An optical frequency comb or mode-locked fiber laser is a very precise for an optical frequency measurement [1]. It is useful in ultrashort lasers and it can measure wide range than other tools [2]. Due to this revolutionary technique, the practical realization of SI-meter has also been modified. Normally, the frequency-stabilized lasers have been recommended by the Bureau International des Poids et Mesures (BIPM) for the practical realization of meter [3]. The National Measurement Institute (NMI) have to bring their frequency-stabilized lasers to join in a key comparison held by the Consultative Committee for Length (CCL) or their own Regional metrology organizations (RMOs) to prove their equivalence of realization of SI-meter. Nowadays, many NMIs have their optical frequency comb. The validation of optical frequency measurement capability of frequency comb is a critical concern for mutual recognition. The proper way to confirm NMI competent is the comb-comb direct comparison. In 2013, Center for Measurement Standards (CMS), Taiwan, and National Metrology Institute of Japan (NMIJ), Japan, did the international comparison by comparing a CMS’s portable frequency comb to a NMIJ’s frequency comb and the result shows that both frequency comb are consistency [4]. In this paper, the fiber laser combs developed by CMS was shipped to NIMT to validate the measurement conformity of CMS fiber laser comb and NIMT fiber laser comb. The results of the comb comparison are reported.

2. Optical frequency comb

The optical frequency comb emitted the electric field in a series of modes, regularly frequency space, and phase coherent with each other. The optical frequency, $f_n$, of the comb line is $f_n=nf_{\text{rep}}+f_0$, where $n$ is an integer, $f_{\text{rep}}$ is a pulse repetition rate frequency and $f_0$ is a comb offset pulse-to-pulse phase shifted frequency. The frequency comb in frequency domain and time domain are shown in figure 1(a) and 1(b) respectively.
Figure 1. (a) Frequency train with evolving phase in frequency domain. (b) Pulse train with evolving phase in time domain.

The optical frequency comb can measure an unknown laser frequency by beating technique. When the unknown laser beat with optical frequency comb, the laser will beating with one of comb line as shown in figure 2. The optical frequency of laser can be identified by

\[ f_{\text{laser}} = nf_{\text{rep}} + f_{\text{0}} + f_{\text{beat}} \]

Figure 2. The optical frequency measurement using optical frequency comb

3. Experimental setup

The own-developed CMS fiber laser comb with repetition rate of 250 MHz was brought to NIMT for optical frequency comparison. The NIMT optical frequency comb is a FC1500-250-WG from Menlo GmbH with a 250 MHz repetition rate. A 633 nm offset lock laser from Neoark (NEO-OL101K) is a measurement artifact for this comparison.

The setup for the NIMT-CMS comb comparison is shown in Figure 3. Both of NIMT and CMS comb are phase-locked to the 10 MHz signal from Cesium clock linked to the Coordinated Universal Time of NIMT (UTC-NIMT 10 MHz signal). The 4th harmonic of the repetition frequency of the CMS comb and NIMT comb are phase-locked to a 1 GHz reference signal multiplied from the UTC-NIMT 10 MHz signal. The output of CMS comb from supercontinuum can adjust to 633 nm and beat with offset lock laser is locked at 20 MHz.

The NIMT comb has a central wavelength at 1550 nm and generate 400 to 900 nm broadband spectrum by Photonic crystal fiber (PCF). The selected spectrum beat with offset lock laser for optical frequency measurement. The optical frequency of the offset lock laser is calculated from the measured beat frequencies, comb offset frequencies and the settings of the repetition frequencies [5, 6].
4. Result

The optical frequency of offset lock laser is determined from both laser comb. Figure 4 shows the measured frequency differences of the two combs. The average of the difference frequencies is 283 Hz and corresponds to a relative difference of $6.0 \times 10^{-13}$ over 2000s.

Figure 4. (a) Beat signal of NIMT comb (b) Beat signal of CMS comb and (c) difference frequency of both comb
5. Conclusion
The NIMT-CMS optical frequency measurement was perform. The difference of average frequency measurement is 283 Hz and corresponds to a relative difference of $6.0 \times 10^{-13}$, which is smaller than frequency-stabilized lasers technique. The absolute measurement by optical frequency comb is the most accurate optical frequency determination at present.

References
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