Parametric Optimization of the Practical Mixer Device in the Optical Comb Frequency Transfer System

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***Abstract*—Mixer is of crucial importance in evaluating the precision of the frequency transfer. We present preliminary results on the optimization of the practical mixer's LO and RF input power parameters when performing downconversion. A fractional frequency instability better than 2E-13@1 s via 100 km fiber link with 100 MHz repetition frequency optical comb is measured under the optimized parameters.**

***Index Terms*—mixer, optical comb frequency transfer, fractional frequency instability**

I. INTRODUCTION

Ultra-precision long distance frequency transfer is to precisely transfer the quantum frequency standard based on atomic clock or optical clock via commercial fiber system [3] or free space [6], using methods such as radio frequency modulation, direct optical frequency transfer and optical comb transfer [2]. Frequency transfer finds its important applications in the field of long baseline interferometry, clock-based geodesy, tests of fundamental constants and so on [4].

In order to assess the precision of the transferred frequency signal, one needs to evaluate its fractional frequency instability with Allan deviation [1]. However, since the precision of the frequency counter, whose limitation on fractional frequency instability is typically 1E-11@1 s, is insufficient to perform such measurement on ultra-stable frequency, the procedure commonly requires beating of two signals, namely, the transferred and the local signals, which is called the beating method (i.e. heterodyne method in [2]) for simplicity. In the beating method, the electronic device mixer plays a central role, because with it one can easily evaluate the phase noise of the transferred signal.

However, the practical mixers, such as the typical double-balanced mixer, has two asymmetric input ports LO (Local-Oscillator) and RF (Radio-Frequency) when performing downconversion, which behave differently [5]. The LO port has a threshold input power, and the dependence of the IF (Intermediate-Frequency) output power on the RF input power is partially linear. These properties both affect the instability of the output signal significantly, which may cause the failure to evaluate the instability of the transferred signal directly from the IF output. Thus, the appropriate parameters of the two input powers are of great importance. We experimentally analyze and optimize these parameters. Moreover, a 100 km frequency transfer system based on optical comb is built, and the instability under these optimized parameters is evaluated.

II. EXPERIMENTAL SETUP

Fig. 1 shows the experimental scheme of the frequency transfer system based on optical comb. The frequency optical comb, with 1550 nm wavelength and 100 MHz repetition rate, splits into two beams with the 50:50 splitter, one of which is transferred to the remote user via optical fiber link, detected by the photodetector (FPD310-FC-NIR), and then with a lowpass filter (Mini-Circuits BLP-150+), we get a 100 MHz sinusoidal signal $V_{\mathrm{R}}\cos(\omega t + \varphi_{\mathrm{f}})$, where φ_{f} is the noise brought by the fiber link. We use two attenuators to adjust the input signals power in LO and RF ports. The LO port input signal is $V_{\mathrm{L}}\sin(\omega t)$. The ideal output of the mixer (i.e. IF port) is:

$$\begin{aligned} V_{\mathrm{I}}(t) &= V_{\mathrm{R}}\cos(\omega t + \varphi_{\mathrm{f}})V_{\mathrm{L}}\sin(\omega t) \\ &= V_{\mathrm{O}}(\sin(2\omega t + \varphi_{\mathrm{f}}) - \sin(\varphi_{\mathrm{f}})) \end{aligned} \tag{1}$$

After passing a lowpass filter EF124, the final output voltage $V_{\mathrm{O}}\sin(\varphi_{\mathrm{f}})$ is measured by the $6_{1/2}$ digital multi-meter (DMM). And φ_{f} can be deduced via:

$$\varphi_{\mathrm{f}}(t) = \arcsin(\frac{V_{\mathrm{I}}(t)}{V_{\mathrm{O}}}) \tag{2}$$

the instant frequency deviation is:

$$\frac{\Delta f}{f_0} = \frac{1}{2\pi f_0}\frac{\mathrm{d}\varphi_{\mathrm{f}}(t)}{\mathrm{d}t} \tag{3}$$

and then we can calculate Allan deviation from the frequency deviation to evaluate the instability of the transferred frequency signal.

If the fiber link is 0 km, it's called back-to-back experiment, a method to measure the noise floor brought by the asymmetry of the two electronic pathways. In our experiment, we first use

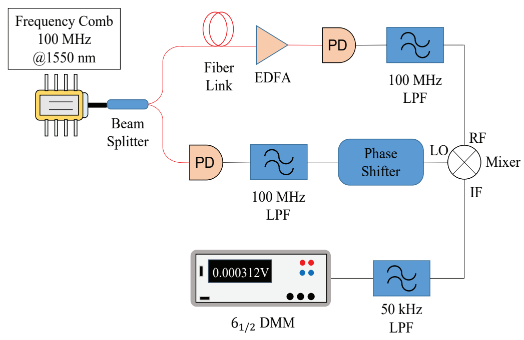

Fig. 1. The experimental setup of the optical comb frequency transfer system based on fiber link. The measurement of instability is based on the beating method.

the back-to-back method with the typical mixer (Mini-Circuits ZAD-3+) to optimize the input power parameters, and then apply these optimized parameters to a 100 km fiber link to measure its fractional frequency instability.

III. INSTABILITY RESULTS

We first measure and verify the dependence of the output power to the RF input power. As shown in Fig. 2, we have a 1-dB compression point, and the following experiments show that the input power of the RF port should be within the linear range. Since the input power of the two ports LO and RF are the key parameters, we therefore study and optimize these two parameters separately.

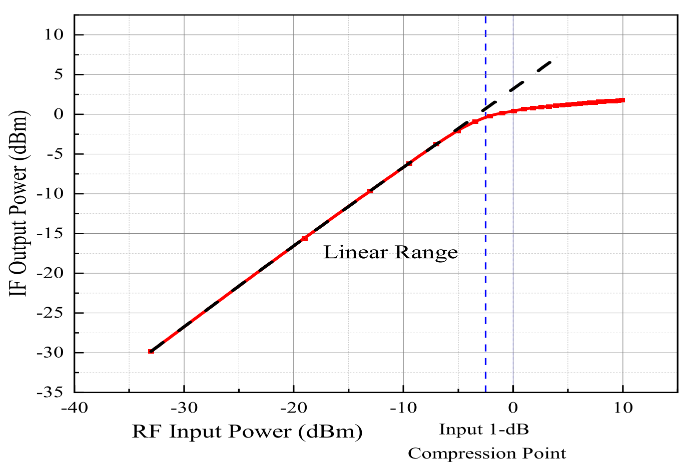

Fig. 2. Dependence of the mixer's output power on the RF input power. The LO input power is set to 7 dBm. The curve has a linear portion and an input 1-dB compression point near -2.5 dBm.

A. Instability dependent on the RF Input Power

First, we fix the input 100 MHz frequency signal in LO input to be 7 dBm and adjust the power parameters of the RF input to be -13 dBm, -7 dBm and 8 dBm. The first two are within the linear portion, while the third one is within the nonlinear portion. Fig. 3 shows the Allan deviation result. We conclude directly from the figure that the mixer behaves similarly in the RF input linear range while far from the ideal mixer in the nonlinear range, indicating that setting the RF input power value far beyond the linear range would result in the failure to evaluate the instability of the transferred frequency signal with the above method derived from the ideal mixer.

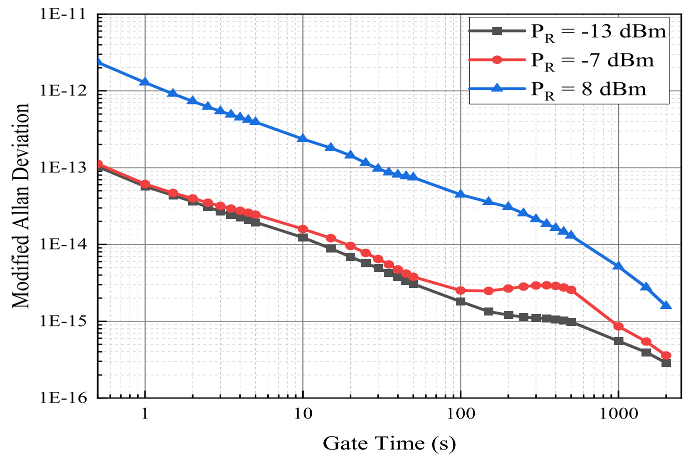

Fig. 3. Dependence of the measured instability results on different RF input power parameters -13 dBm, -7 dBm and 8 dBm. The LO input power is fixed on 7 dBm.

B. Instability dependent on the LO Input Power

The power of the input 100 MHz frequency signal in RF input is fixed to be -7 dBm, which is within the linear range. Then, with the power parameters of the LO input to be -23 dBm, 7 dBm and 17 dBm, which are three typical values below, near and over the threshold respectively, we show in Fig. 4 the Allan deviation results. Clearly, when the LO input power is near the threshold, the mixer behaves more closely to the ideal case, thus making the derivation above the most accurate to evaluate the instability of the transferred frequency signal.

We then use these optimized parameters to evaluate the stability of the 100 km fiber path optical comb frequency transfer. In Fig. 5, the 100 km measurement result 2E-13@1 s is given, as well as its comparison to the back-to-back result and the noise floor of the $6_{1/2}$ DMM (Keysight 34465A).

IV. CONCLUSIONS

We have presented preliminary results about the optimization of the input power parameters when performing down-conversion by mixer. The optimized input power of the RF port should be within the linear range and that of the LO port should be near the threshold value. Under these optimized parameters, we evaluate the fractional frequency instability of the transferred signal via 100 km fiber with the beating

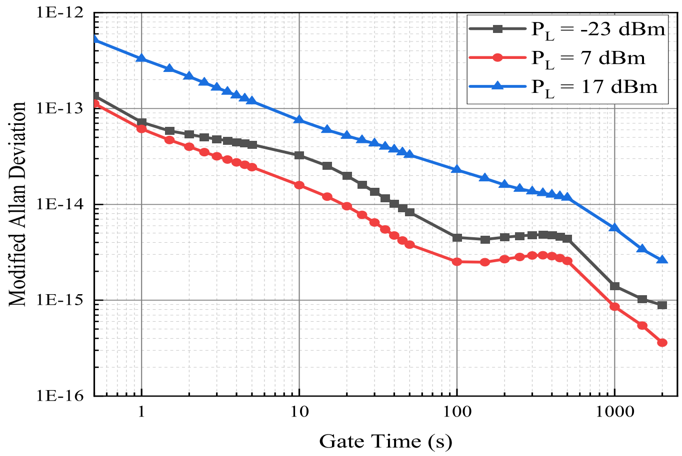

Fig. 4. Dependence of the measured instability results on different LO input power parameters -23 dBm, 7 dBm and 17 dBm. The RF input power is fixed on -7 dBm.

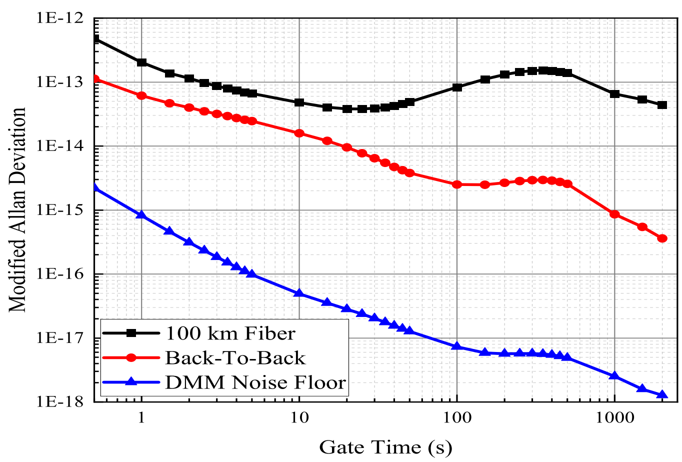

Fig. 5. The instability result of 100 km fiber optical comb frequency transfer, under the optimized parameters of the mixer's input power. The $6_{1/2}$ DMM noise floor and the back-to-back instability results are also drawn here to give a comparison.

method, and the result gives 2E-13@1 s. In the future work, we will optimize the optical comb source and the fiber link to further improve the stability of the transferred signal.

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