A Technique of Ultra High Frequency Measurement

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***Abstract*—In the frequency comparison, two signals with multiple relations in frequency can be synchronal. This means that in a specific time interval, their phase will be periodically coincident. The general case is that, when minute frequency difference existing in the two signals with multiple relations in frequency, coincidence points of them will move forward or backward. The coincidence points can be strictly fixed in comparison between the two compared signals with exact integral multiple relations in frequency. The position change of this coincidence indicates the relative change of the phase difference of signals. With big frequency ratio condition, the ultra high frequency can be obtained from lower frequency signal that has the multiple relations with it and the relative change of their phase. An experiment demonstrating this technique was designed through phase processing method at GHz, in which the lower frequency signal was reshaped into a narrow pulse on a particular position of every period and be the sampling signal of the high frequency signal, and the high frequency was obtained indirectly through recording the position of the slowly moving coincidence points. With the improvement of frequency response of the coincidence measurement circuit, even higher frequency can be measured.**

This is the same as the signal relations in many atomic frequency standards and it will be very useful in signal processing and circuit improvement of atomic frequency standard.

I. INTRODUCTION

In most cases, the phase comparison is used between two signals with the same nominal frequency. The characteristics of the minute frequency difference between the two compared signals can be gained through analyzing the periodic information of the phase difference. With the big ratio of two signals of different nominal frequencies, phase comparison also can be used between the period of the low frequency signal and multi-period of the high frequency signal. Analogous comparison results can be obtained, which proves to be periodic as well[1]. This technique is available in high frequency measurement through detecting the minute frequency difference between two signals with multiple relations.

This paper was supported by the National Science Foundation of China under Grant NO. 60571060 and Xidian Graduate Innovation Project

II. THEORY OF PHASE COMPARISON BETWEEN SIGNALS WITH MULTIPLE RELATIONS IN FREQUENCY

Assuming v_H , v_L are frequencies of the two signals respectively. If they are of multiple relations, we can set it as M, and then $v_H = Mv_L + \Delta v$, and Δv is the minute frequency difference between v_H and Mv_L . The period of the low frequency signal can be expressed as $T_L = MT_H + \Delta t$, where Δt is the minute time difference between T_L and MT_H . In a T_L period, Δt is too small to be measured. The method of cumulating Δt into longer time interval, named Δt_n , is used here, and the frequency difference Δv can be calculated accurately using the following expression [2],

$$\frac{\Delta v}{v_H} = \frac{\Delta t_n}{\tau} \qquad (1)$$

Where τ is the longer time interval in which Δt is accumulated to Δt_n .

The experiment using Lissajous curves displayed on an oscilloscope had been done before to verify the principle [3], in which the time interval between the two points of stable waveform was recorded, while the time interval measurement of it is inconvenient and the oscilloscope is necessary, which makes it difficult to implement.

III. DESIGN OF HIGH FREQUENCY MEASUREMENT USING PHASE COMPARISON METHOD

Based on the previous work [2][3], we implemented the principle above with phase coincidence detection circuit. In this paper, the minute time difference is reflected in the coincidence points and the relative changing tendency of their position. With the high frequency coarsely measured, the accurate value of the high frequency can be gained by recording the longer time interval Δt_n in which the coincidence points move from one detection point to the adjacent one.

A. System structure

The signals of high frequency and low frequency are sent to coincidence detection circuit. The coincidence points can be strictly fixed and appears periodically at the same detecting point if the two signals in comparison are of exact integral multiple relations in frequency. Actually, it is ideal and appears scarcely. Generally, minute frequency difference exists between Mv_L and v_H , and the coincidence points of them move forward or backward. Record the time interval in which the coincidence points move from one detection point to the adjacent one, and the accumulated phase difference can be deduced from the standard length of the transmission line[4], so the time interval for the accumulation can be measured through a time counter. Figure 1 shows the configuration of the system.

B. Coincidence detection circuit

The key component of the experimental system is detection of the phase difference. In which the method of phase coincidence detection was used, as shown in figure2.

When traveling in the transmission circuits, the peak of the low frequency signal may appear between any two peaks of the high frequency signal in most cases and, occasionally the coincidence occurs when two signals reaches their peak values simultaneously, named coincidence point. The high frequency signal to be measured and the low frequency signal are sent to the transmission lines, in which the one used to transmit high frequency signal is constructed with small transmission segments of equal length. At the end of each segment it sets the coincidence detection circuits, to capture the exact position when the phase difference approaches zero under ideal

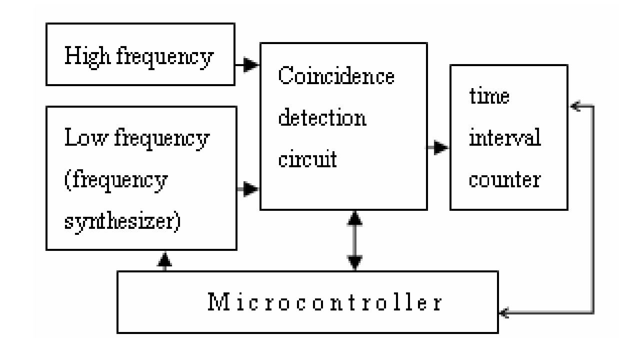

Figure 1. Block diagram of the system construction

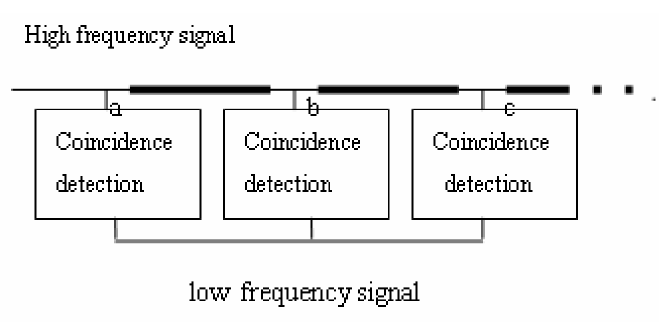

Figure 2. The detection circuit of coincidence points

conditions. The low frequency signal is reshaped into a narrow pulse signal and sent into the detection circuit simultaneously, i.e., the coincidence detection at any points occurs at the same time. The delayed signal of high frequency involves in the phase comparison with the low frequency signal at the points a, b, c…. Figure 3 shows the waveforms of every detection point, as well as their relative phase variation.

Assuming the coincidence point appears at point b, it is stable if the two compared signal with exact integral multiple relation in frequency, while it will move towards a or c if there is a minute difference Δv existing, positive or negative. With the minute difference Δv between Mv_L and v_H , it seems like the waveform of the high frequency signal moves a certain length in the transmission line in each T_L period. We can get equation (2) based on equation (1),

$$\frac{\Delta v}{v_H} = \frac{t}{nT_L}$$

(2)

Here, t is the delay time of the transmission line, which corresponds to the accumulated time difference when the coincidence moves from b to c or a, and nT_L is the relevant comparison time.

C. Experiment results

In our experiment, the length of each transmission line is 5cm, of which the delay time t is 250ps. The ECL edge-triggered flip-flop was chosen to be the logic unit carrying out the comparison and communicating with data acquisition and processing instrument. Position of the rising edge, indicating that of the coincidence point, was recorded and sent to the computer.

To accurately measure the high frequency, the time interval Δt_n in which two coincidences occur was recorded by a time interval counter. The comparison between signals with nominal frequencies of 1MHz and 100MHz were chosen as the demonstration of the high frequency measurement system. The experimental data taken by the time interval counter are shown in table 1. Here v_H' is the high frequency measured in our experiment system, and v_H'' is the high frequency measured directly by a frequency meter of high resolution [5].

From the experiment results, we can see that, the measurement results gained in our measurement system accord with that by the frequency meter with 1s gate. And the measuring resolution in our experiment is higher than that of the frequency meter. The length controllable transmission line is used here to adjust the comparison time, which can be shortened by changing the length of the transmission line when the comparison time is too long to measure, that is, the measurement range is expanded indirectly.

D. Error analysis

From equation (2), we can get that, the measurement error in our experiment is mainly caused by the instability of the delay time for the 5cm transmission line. Based on the

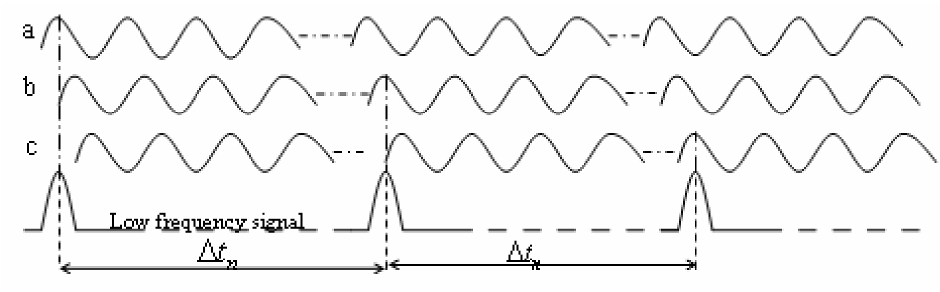

Figure 3. Waveforms on coincidence detection points

experiments on the delay time of transmission line varying with temperature, the variation of the delay time for the 5cm transmission line is 0.025ps/℃, which results in an error of $\frac{0.0025}{nT_L}$(Hz) in frequency measurement, and it approximates an error of 3×10^{-11}Hz in our proving experiment.

IV. CONCLUSION

In this paper, the technique of phase comparison between two signals with multiple relations is used here, and based on it the high frequency can be measured with the low frequency signal whose nominal frequency is known and the integral multiple coarsely measured. The frequency relations of the two compared signals are the same as that of signals in many atomic frequency standards, and with the development of the detection and measurement, it can be used to simplify the signal processing circuit in atomic frequency standard if the bandwidth of the detection circuit satisfy the requirement of the high frequency signals.

TABLE I. MEASUREMENT RESULTS OF HIGH FREQUENCY

τ (ms)	$\frac{\Delta v}{v_H}\left(10^{-9}\right)$	v_H' (MHz)	v_H" (MHz)
77.812	3.2128	99.99999967872	99.9999996825
76.239	3.2791	99.99999967209	99.9999996747
76.341	3.2747	99.99999967253	99.9999996767
77.241	3.2341	99.99999967659	99.9999996786
76.080	3.2859	99.99999967141	99.9999996725

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