Comparison between Analog and Digital Time and Frequency Measurement Techniques

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***Abstract*—Along with the accuracy enhancement of different kinds of frequency standards, more demands are made on the measurement precision. In time and frequency measurement instruments, both digital and analog processing techniques and circuits are used widely.**

The paper focuses primarily on the limitations of the technology and the principle in the use of the analog and the digital measurement approaches. Based on the principle of the conventional method measuring the period of frequency difference between the reference and the measured frequency standards, the analog and the digital measurement techniques are compared in actual realization, configuration, precision and error sources etc. A number of experiments indicate that the precision of the analog method is as high as 10-13/τ and the precision of the digital method about 10-12/τ or lower. Furthermore, the digital scheme in TTL circuits has great influence of trigger error and quantified error on measurement result; while in ECL circuits, trigger error is held down and the precision is greatly enhanced.

Moreover, this paper proposes some improvement step. One had better appropriately combine ultra-high speed devices with the digital method to obtain a high precision frequency measurement device.

I. Introduction

Among the high precision comparison methods between frequency standard signals, both the analog processing method and the digital processing method are used widely. For the perfect combination of high precision, high resolution, simple construction and low cost, it is necessary to quantitative analysis and comparison. Both the analog and the digital scheme on the traditional frequency difference method are realized in the paper. The phase relationship is used to process signal in the digital scheme, which respectively carry out in TTL and ECL circuits in the paper.

Some available high performance devices have been utilized, which are the frequency synthesizer, HP8662A, the universal counter, SR620, the high stability crystal oscillator, 1250A.

II. Frequency Standard Comparison Scheme in Analog Processing

The measurement method in the analog scheme is a conventional method improved in recent years, which is more complex in debugging than the digital scheme. It is the main reason that the use of analog method is gradually decreased recently years. However, it still has rather high accuracy and resolution. Because of the working principle of analog mixer, the nominal frequencies of signals compared between each other should be same. So, the band width of mixer in analog is narrower.

The frequency comparison system with analog mixer is shown in Figure 1.

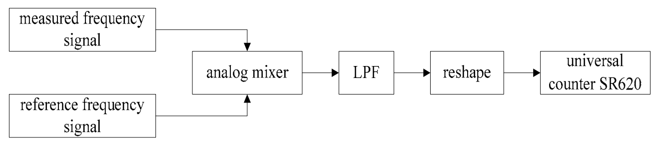

Figure1. Block diagram of frequency comparison system with analog mixer

III. Frequency Standard Comparison Scheme in Digital Processing

Large numbers of digital or logical circuits is indispensable in frequency comparison and measurement devices. Besides those own logical functions, the function of time and phase processing of digital circuits can also be made use of. The practical process of digital measurement is that the digital signal converted from the analog signal is processed, measured and done other operation on. The process is characteristic of time processing function of digital device.

The frequency comparison system with digital mixing device is shown in Figure 2. Two frequency standard signals, mixed with each other in digital mixing device, are reshaped.

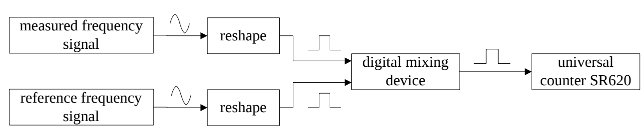

Figure2. Block diagram of frequency comparison system with digital mixing device

In this scheme, the digital mixing function is carried respectively out with TTL circuits and ECL circuits.

IV. Test Results and Its Analysis

Based on the above two schemes, a number of experiments for measuring frequency stability have been

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done. Each result datum is the Allen variance of 101 measuring data.

In the first experiment, the high stability crystal oscillator, 1250A, is the measured frequency standard and the output of the frequency synthesizer, HP8662A, is the reference frequency. Moreover, the frequency of the output of HP8662A is respectively 10Hz, 100Hz and 1000Hz higher than 1250A. Then, the period of the frequency difference signal have been measured respectively through the analog and the digital method. The digital method utilized 74LS74, D flip-flop in TTL circuits. Test results, including results in self-correction (SC) are shown in Table 1 and Table 2. It is the self-correction that the measured frequency standard is related with the reference frequency standard, which would produce less interference of the instability of two frequency standards on precision.

In the second experiment, the output of the frequency synthesizer, HP8662A, is the measured frequency standard and the inner frequency standard (10MHz) of HP8662A is the reference frequency. This is a self-correct measurement. The following operation is a repetition as the first experiment. Its test results are shown in Table 3 and Table 4.

Table 1 Test results in digital scheme, f_r=5MHz, TTL

Frequency Bias		10Hz	100Hz	1kHz
Gate Time	1s	3.50×10^{-11}	3.36×10^{-11}	3.60×10^{-11}
	1s(SC）	1.20×10^{-11}	2.22×10^{-11}	3.84×10^{-11}
	10s	4.03×10^{-12}	4.22×10^{-12}	---
	10s(SC)	4.12×10^{-12}	4.80×10^{-12}	---

Table 2 Test results in analog scheme, f_r=5MHz

Frequency Bias		10Hz	100Hz	1kHz
Gate Time	1s	1.90×10^{-12}	2.40×10^{-12}	1.02×10^{-11}
	1s(SC）	1.30×10^{-12}	1.47×10^{-12}	9.60×10^{-12}
	10s	1.25×10^{-12}	1.32×10^{-12}	---
	10s(SC)	5.17×10^{-13}	3.74×10^{-13}	---

Table 3 Test results in digital scheme, f_r=10MHz,TTL

Frequency Bias		10Hz	100Hz	1kHz
Gate Time	1s	1.36×10^{-11}	2.50×10^{-11}	3.18×10^{-11}
	10s	1.60×10^{-12}	2.14×10^{-12}	---

Table 4 Test results in analog scheme, f_r=10MHz

Frequency Bias		10Hz	100Hz	1kHz
Gate Time	1s	1.34×10^{-12}	1.87×10^{-12}	1.03×10^{-11}
	10s	9.63×10^{-13}	5.52×10^{-13}	---

In the two above experiments, under the same conditions, the results of the analog scheme are an order of magnitude better than that of the digital scheme, close to the highest system resolution.

According to the literature [1], the high performance quartz oscillators should be characteristic of the similar Allen variance in a second, in 10 seconds and in the interval between them. In Table 2, the frequency stability in a second respectively is similar as that in 10 seconds when the frequency bias is 10Hz and when the frequency bias is 100Hz, which is also brought forth in Table 4. The above indicates that the datum got from the analog scheme is credible and can achieve the frequency stability according to the facts. However, when the frequency bias is 10Hz in Table 1 and Table 3, the frequency stability in 10 seconds is an order of magnitude better than in a second, which is the same as 100Hz; the stability of 10Hz and 100Hz of the frequency bias in 10 seconds is the same order of magnitude as the corresponding results in the analog scheme. That is, the measuring results in the digital scheme are seriously related to the gate time. With the gate time changing, the measured frequency stability is changing. Therefore, compared with the analog scheme, the digital scheme will achieve the results greatly different from the true value of the measured frequency standard, which has no way to reflect the true value.

Three factors on precision measuring the period of frequency signals are as follows. 1. The stability of the inner crystal oscillator of frequency counter; 2. ±1 word count error, which can be reduced by expanding the period of measured signal and heightening the frequency of reference frequency standard; 3. Trigger error, which is determined by the noise of the measured signal. With the same counter, the first factor has the same influence on the two schemes. In the above two experiments, the results in the digital scheme are still an order of magnitude lower than them in the analog scheme even if self-correction. Although the results in the digital scheme are better by increasing the gate time, they are still of the order of 10^{-12}. Hence, in the digital scheme with TTL circuits, the trigger error seriously influences the measuring results; it is difficult to improve measuring precision just by increasing the gate time and reducing ±1 word count error.

In view of characteristics in the design of ECL integrated circuits, D flip-flop in ECL circuit is used as a mixer. In the third and the fourth experiment, D flip-flop, MC10131, is used. The gate time is 1s.

In the third experiment, 1250A is made as the outer frequency standard of HP8662A and its output is compared with the output of HP8662A. The output frequency of HP8662A is tuned to be respectively 10Hz, 100Hz and 1000Hz higher than 5MHz, 10MHz, 20MHz, 30MHz, 40MHz and 50MHz. Test results are shown in Table 5.

In the fourth experiment, the inner frequency standard of HP8662A, 10MHz, is used as the reference frequency signal. The output frequency of HP8662A is tuned as the measured frequency, which is the same as that of the third experiment. Test results are given in Table 6.

These two experiments are self-correct and belong to the typical harmonic mixing method. All of the measuring results in Table 5 and Table 6 are better than Table 1 and Table 3. Because the signal amplitude in ECL circuits is smaller and the signal is given directly into D flip-flop in ECL, besides the own noise of devices the measured signal wouldn't be interfered by any interferences. While, as for the digital scheme, the signals reshaped as the square wave in ECL in the first and the second experiment are reshaped again to be the square wave in TTL. During the above process, extra noise and disturbance will be introduced and be inputted into D flip-flop in TTL, which will cumulate more error so as to augment the trigger error. The digital scheme in ECL circuits can depress the influence of trigger error. Furthermore, a better measuring precision of harmonic mixing at higher frequency could be realized in the scheme of ECL, which is the strong guarantee of wide-band frequency measurement.

Obviously, the analog scheme has less error than the digital scheme. Analog mixing is strictly mixing process; while digital mixing is a macro-reflection of signal process on time and phase in digital devices, in which ±1 word count error and trigger error can not be ignored. In the digital frequency difference comparison system, trigger error is restricted in a certain extent, so ±1 word count error is the key problem for improving measuring precision.

Table 5 Test results of the third experiment, in digital scheme, f_r=5MHz, ECL

Frequency Bias	10Hz	100Hz	1000Hz
5MHz	7.6×10^{-12}	8.6×10^{-12}	2.4×10^{-11}
10MHz	9.0×10^{-12}	1.3×10^{-11}	2.6×10^{-11}
20MHz	1.3×10^{-11}	1.8×10^{-11}	3.0×10^{-11}
30MHz	1.4×10^{-11}	2.1×10^{-11}	3.6×10^{-11}
40MHz	2.3×10^{-11}	2.6×10^{-11}	4.2×10^{-11}
50MHz	2.5×10^{-11}	3.3×10^{-11}	4.2×10^{-11}

Table 6 Test results of the fourth experiment, in digital scheme, f_r=10MHz, ECL

Frequency Bias	10Hz	100Hz	1000Hz
10MHz	3.3×10^{-12}	5.5×10^{-12}	7.8×10^{-12}
20MHz	3.9×10^{-12}	5.8×10^{-12}	8.3×10^{-12}
30MHz	4.6×10^{-12}	6.4×10^{-12}	8.7×10^{-12}
40MHz	4.9×10^{-12}	6.5×10^{-12}	1.0×10^{-11}
50MHz	6.1×10^{-12}	8.8×10^{-12}	1.5×10^{-11}

V. IMPROVED TECHNIQUES

For the convenience of discussion, it is necessary to determine the definition of mixing and harmonic mixing in the phase and time process. With the phase difference of two signals changing monotonically the period of the beat signal is strictly equal to the interval between two adjacent phase-coincidence points, which is mixing. As for two signals with integral multiples, whose phase difference is changing monotonically, the period of the harmonic beat signal is strictly equal to the interval between two adjacent phase-coincidence points, which is harmonically mixing. The following is all based on the above definitions.

Aimed at the operation of D flip-flop with different phase difference, when the raising edge of Q is coming in Figure 3, the fine change of phase difference between the inputs of D and CP is able to more carefully reflect the phase relation of two compared signals. In each of Figure 3, where the phase coincidence point would appear is respectively given with different phase difference in square wave. Let f_0 to be the frequency of CP pulse and T_0 to be its period; Let $f_x=f_0+\triangle f$ to be the frequency of D pulse and T_x to be its period; Their period difference is $\triangle T=1/\triangle f$. As Figure 3(a) shows, the phase coincidence point should be found at the zero-phase point of the former CP cycle with the phase difference of $\triangle T$; In Figure 3(b), the phase coincidence point should appear at 3/4 of the former CP cycle; the rest may be deduced like this so it is the zero-phase when the rising edge coincides with the phase coincidence point.

Consequently, for getting the accurate period of the beat signal or the harmonic beat signal, that is the interval between the two adjacent phase-coincidence points, the phase relationship between signals, at the edge of the beat signal or the harmonic beat signal, should be acquired to deduce the position of the phase coincidence point. Some obstacles [2] [3] still exist to be resolved.

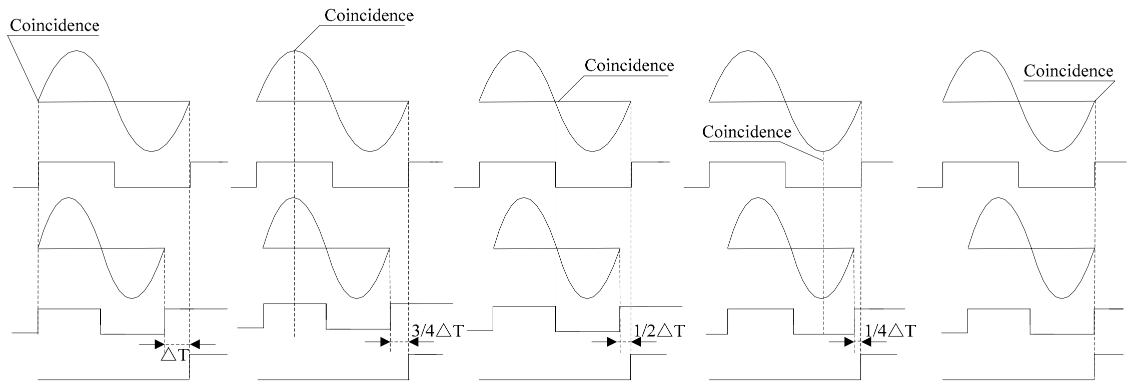

Figure3. Phase coincidence state of different phase difference between the inputs of D and CP

VI. CONLUSION

With the traditional frequency difference method as the experiment plat, lots of experiments are made to compare the digital process with the analog process. Under the same principle and experiment condition, the resolution of the digital scheme is about 10 times lower than the analog scheme. But the analog scheme is only used on the comparison between frequency standards with same nominal frequency and its debugging is complex and even complicated. The digital scheme is convenient in use and broad in measure range. Experiments show that the digital scheme in TTL circuits has great influence of trigger error and quantified error on measurement result; while in ECL circuits, trigger error is held down and the precision is greatly enhanced. However, when mixing or harmonic mixing, ±1 period error of lower frequency signal is inevitable to confine measure resolution and precision. The paper made a detailed discussion on quantified error in phase processing and refers to a thought for resolving. The improvement can achieve the order of ps in theory.

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