# A Novel Phase Processing Approach Based on New Concept and Method

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***Abstract*—Conventional phase processing is only for the continuous phase comparison at the same nominal frequency. In this case the processing resolution is limited, PLL and synthesizer are complicated, and linking between ultra high and ultra low frequency signals is very difficult. In most cases the comparison and control of frequency signals occur between the different nominal frequencies. To two signals with different nominal frequencies, one is the reference signal and another is the measured and controlled signal. The phase variation period of them is their least common multiple period, $T_{minc}$ (LCMP), and also expresses the phase variation of the measured signal against its nominal frequency signal. In $T_{minc}$ between two period groups of the signals the average variation full period of all different phase differences is equal to the group phase variation between any two most adjacent phase coincidences. It is also equal to 1/AB $T_{minc}$, the equivalent phase comparison period $T_{equ}=T_{minc}/AB$. Here A and B are the divider between nominal frequency of the signals and their greatest common factor frequency (GCFF) respectively.**

**Theoretically, the direct phase comparison can be completed between any different frequency signals, and the resolution can be very high.**

**With a lot of experiments, the phase processing principle and approach have been proved to show some very important application values, for example, with higher frequency and phase measurement resolution, high-precision and more flexible PLL technique, and so on. The approach has been used in high-resolution frequency measurement instruments, high-precision PLL and phase measurement and control devices. It is easy to obtain ps to fs resolution and the frequency and phase processing is more flexible. With the approach the frequency signals with a big frequency difference, for example, even more than $10^5$ times, can be compared and processed directly.**

## I. INTRODUCTION

Phase comparison in time and frequency measurement and control can show the highest resolution. The measurement, comparison and control of frequency signals are based on the correlation of time and frequency, so it's very important to obtain high precision characteristics from the correlation of signals. Here the correlation of phase between frequency signals will bring about a better result. Conventional processing of phase difference is base on the sequence phase change between signals with the same nominal frequency, but its premise is the frequency normalization and the comparison precision is usually limited. Therefore, phase comparison is often accompanied by complex frequency transformation [1]. A typical example just is the frequency transformation circuit of active atomic frequency standard.

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## II. SOME CONCEPTS OF THE CORRELATION CHARACTERISTICS BETWEEN FREQUENCY SIGNALS TEMPLATE

Besides the respective periodic variation of frequency signals, measurement, comparison and control are mainly affected by the regular change of phase difference and some concepts derived form it, which are Greatest Nominal Common Factor Frequency (GCFF), Least Nominal Common Multiple Period (LCMP), Quantized Phase Shift Resolution (QPSR), Equivalent Phase Comparison Period (EPCP), Equivalent Phase Comparison Frequency (EPCF) and group phase difference variation between corresponding periodic groups and so on [2][3].

Usually the phase difference variation between signals with the same nominal frequency is serial, but it is obvious that the phase difference between arbitrary frequency signals is not. So phase can't be compared between two different frequency signals, and it is shown in Fig.1.

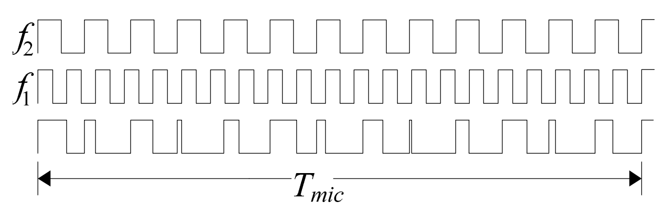


Figure 1. A common phase difference distribution in one$T_{mic}$

In one LCMP, phase differences are different with one another. If the compared signals are divided into groups by $T_{mic}$ from time, the average of all the phase differences in a $T_{mic}$ corresponding to the two compared signals is the group phase difference. It can be seen in Fig.2.

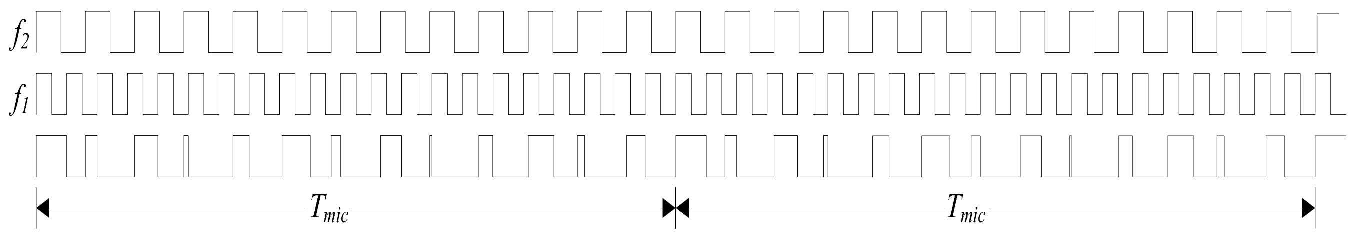


Figure 2. Group phase difference of compared signals in the period of $T_{mic}$

The group phase difference has obvious characteristics. It takes $T_{mic}$ as a unit for analysis and the average variation is serial. The full period of the phase comparison variation depends on the group phase shift of the adjacent phase coincidence between periodic groups. It is far less than $T_{mic}$ and the period of each compared signals, shown by equation (1).

$$\Delta T = \frac{T_1}{B} = \frac{1}{\mathrm{AB} \cdot f_{\mathrm{maxc}}} \quad (1)$$

The period of group phase shift $\Delta$T signifies very high resolution of periodic phase variation, also called as QPSR. It is also the resolution of the serial phase difference variation. Different relations between frequency signals determine different varying regularity of phase difference, but the QPSR is still follow equation (1).

We define the reciprocal of group phase shift period $\Delta$T as Equivalent Phase Comparison Frequency (EPCF), $f_{equ}$.

$$f_{equ}=\mathrm{A}^*\mathrm{B}f_{maxc} \quad (2)$$

Where A*B is an important parameter that reflects the difference between EPCF and GCFF. Because the frequencies of the compared signals are arbitrary, the bigger the coefficient, the more favorable the improvement of the resolution, but it is more difficult for the phase processing at the same time. In practical application, it is very complex to ascertain A and B by the definition of GCFF. For stable frequency signals, the values of A and B ascertained by nominal values of the two signals are obviously smaller than that ascertained by actual values.

## III. KEY CHARACTERISTICS

EPCF is based on time or phase, it is a frequency corresponding to the repeated phase shift formed by the repeated phase difference variation between two signals, and this frequency is far higher than each of the two signals. It is the reflection of higher resolution of the relative phase and frequency relationships.

Whether EPCF is observed in voltmeter or oscilloscope, the bigger the difference of EPCF with the two compared signals is, the weaker the signal amplitude that reflects the phase coincidence and the period of EPCF.

By equivalent phase comparison between signals of multiple relation or integer ratio relation, we complete high precision comparison between a signal of very high frequency and another signal of lower frequency.

From the definition of EPCF, it isn’t reflected directly in the frequencies of the two signals respectively, but in the phase variation regulation between two signals. However, under the effect of special device, the narrow pulse formed by the phase relation of the two signals may generate the special frequency.

EPCF usually aims at the phase variation characteristics between signals with different nominal frequencies. We use the concept of average phase difference of periodic group instead of conventional sequent phase difference variation processing. The improvement of the concept makes the phase processing technique be used between any frequency signals. So it is flexible and easy to use. Both resolution and the difficulty of information detection should be taken into account.

EPCF includes nominal EPCF and real EPCF, the former is base on the nominal frequencies of the two compared signals; but the latter is base on the real frequencies of the two compared signals, so it is bigger than the former. It is also because that the LCMP value is much lower than each period of the two signals, one real LCMP often includes several nominal LCMPs. In the typical frequency control of PLL, it also shows up that the real LCMP and the nominal LCMP are different, from the work of lock loop they will be completely the same little by little.

For the processing and measurement based on Equivalent Phase Comparison Frequency, we can use the method of pulse average, pulse sample or phase interference. These methods have different comparison and processing resolution, and can be applied in different fields.

The method of pulse average takes LCMP as average period, and we average all the phase differences between the two comparison signals. The whole period of the phase comparison is the period of EPCF, and the resolution of the phase comparison is the highest. But at the same time for too high resolution, the signal detected is weaker and it will be difficult to realize.

The method of pulse sample takes LCMP as interval, and the phase processing is completed based on the sequent arrangement of the phase differences. The whole period phase variation obtained is equal to the period of the signal of the higher frequency. The method can be applied in complex phase processing between any signals flexibly and widely.

The method of phase interference is more suitable for the more complex frequency relation, the frequency relativity and relative phase difference variation can be reflected in image. The whole period of the phase variation equals to the period of EPCF too. From experiments, we already realize the phase interference of $A*B>10^5$ between signals stably, and based on the results we also realize the phase analysis and the measurement and control of large frequency ratio signals.

TABLE I. COMPARISON BETWEEN THE METHODS BASED ON EQUIVALENT PHASE COMPARISON PERIOD AND THE CONVENTIONAL METHOD

| Properties | Conventional method | Method based on EPCP |
|---|---|---|
| Whole period of phase comparison | Nominal period, T | EPCP(pulse average) Period of higher frequency signal (pulse sample) |
| Sequence of phase comparison | Sequence | Interval of LCMP |
| Average detection amplitude | Greater than 1 | Less than 1/AB |
| Average detection resolution | normal | higher |
| Filling detection resolution | Filling pulse period | Filling pulse period |

## IV. SOME USEFUL EXPERIMENT RESULTS

Because of the high resolution of QPSR and EPCP, when the phase difference between the signals is the least we can consider the situation as the phase coincidence between the signals. The gate of measurement or control based on this is very useful for the improvement of the measurement precision and the elimination of ±1 count error. $10^{-15}$/s self-calibration precision and $10^{-13}$/s frequency stability can be obtained in using the device constructed by the principle in Fig.3.

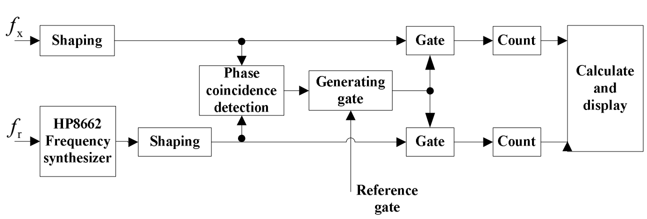


Figure 3. Detecting block diagram of quantizing “phase coincidence”

Table.2 is the results of the self-calibration. The precision will be higher if it is processed in phase analysis. This principle is already used in high precision frequency standard comparison and PLL circuits, and the effect is very good. Because of the noise of the synthesizer, the comparison precision will be lower than the results in Table.2.

With the method of pulse average, all the phase difference between the signals in a $T_{mic}$ can be transformed to corresponding voltage signals. In this way, the period of phase variation is equal to EPCP between the two signals. Because the non-linear narrow pulses and other wider pulses are averaged, the higher phase comparison resolution and better linearity can be obtained, which is the base of the new type of PLL. In high linearity phase comparison, it is required that the product of A and B shouldn’t be too large, so as the new PLL, usually the product is several hundreds.

TABLE II. RESULTS OF THE SELF-CALIBRATION

| Self-calibration frequencies (MHz) | | $\Delta T$ | $f_{equ}$ | Frequency stabilities σ (/s) |
|---|---|---|---|---|
| $f_0$ | $f_x$ | | | |
| 10.000000 | 5.000001 | 19.999996fs | 50.00001THz | $9.13\times10^{-14}$ |
| 10.000000 | 5.00001 | 199.9996fs | 5.00001THz | $1.30\times10^{-12}$ |
| 10.000000 | 5.0001 | 1.99996ps | 500.01GHz | $1.31\times10^{-11}$ |
| 10.000000 | 5.001 | 19.996ps | 50.01GHz | $1.82\times10^{-10}$ |
| 10.000000 | 10.000010 | 99.9999fs | 10.00001THz | $2.77\times10^{-12}$ |
| 10.000000 | 20.000010 | 49.999975fs | 20.00001THz | $7.34\times10^{-13}$ |
| 10.000000 | 100.00001 | 9.999999fs | 100.00001THz | $2.62\times10^{-14}$ |
| 10.000000 | 190.00001 | 5.263fs | 190.00001THz | $5.65\times10^{-15}$ |

Phase interference phenomenon is also useful in the measurement and control. From the time relation, when two signals are from the same frequency source, the phase relation between them is unchanged in $T_{mic}$. And from the wave and phase comparison voltage, the stable phase interference phenomenon appears. If two signals which aren’t from the same source, the phase interference phenomenon is variable. In complex frequency control, it can be achieved by analyzing the phase interference phenomenon instead of the conventional method of frequency normalization. The control signal should be determined by the deviation quantity and its direction of phase interference phenomenon. It is very useful for the measurement, comparison and control between two frequency signals with complex relationship. The typical example of the phase interference phenomenon is the Lissajous curve seen in an oscilloscope. In equation (1), the larger the product of A and B, the higher phase comparison resolution can be observed. But the signal of the phase interference phenomenon is weaker at the same time. Experiments prove that high frequency signal can be measured accurately by analyzing the phase interference phenomenon, even if the product of A and B is larger than $10^5$ [4].

Design of new PLL based on EPCF has been completed. Because of the phase comparability between any two frequencies, it’s not necessary to get the frequency normalized in PLL. To lock the phase of two signals with different frequencies, the EPCF is the key, which can be used to analyze the resolution of phase comparison and control and to determine the frequency locking range. In this way the system structure would be simplified, and the additional noise would be eliminated [5]. The method of pulse average or pulse sampling should be selected reasonably. Finally, the development of this technique will improve the performance of Atomic Frequency Standard greatly.

Fig.4 shows the Lissajous curve created by signals in which one is 10MHz and another is 10.025MHz. The EPCF is 4010MHz, and the period of grid rotation is only corresponding to 0.249ns phase difference variation. This is a typical phase interference phenomenon. Here, the product of A and B is equal to 160400. It is proved that even the product of A and B is larger than $10^5$, the phase interference phenomenon still can be seen clearly by observing the Lissajous curve in oscilloscope. By this method, the phase comparison resolution is a few tenths of 0.249ns. If the phase interference phenomenon is caused by two signals from the same source the grids are stable, otherwise they will be rotatable.

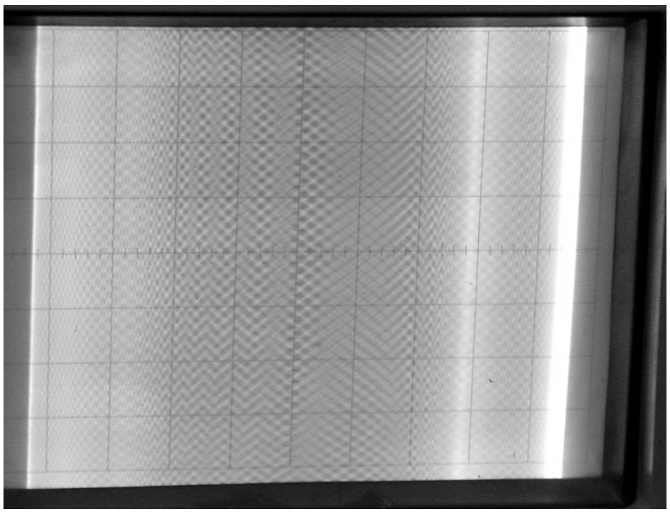

Figure 4. Llissayous curve of signals between 10MHz and 10.025MHz frequencies

This new principle will be used in improvement phase noise measurement technique. With traditional methods to measure the single sideband phase noise of a signal accurately, it is necessary to use a reference signal with the same nominal frequency to it. So a low phase noise frequency synthesizer is needed. With new concept of PLL circuit and technique, we just need a stable frequency signal as reference frequency standard to measure the different frequency signals. So the system structure would be simplified greatly.

## V. CONCLUSION

Based on the analysis of a series of parameters about the relationship of frequency signals, such as GCFF, LCMP, EPCF, QPSR, group period and group phase difference analysis between signals, we can bring certain changes to the traditional frequency measurement, transformation, synthesis, and control techniques. By replacing the traditional sequent phase processing technique, we should use the method of non-sequent phase average and sample to process the non-sequent phase relationship. Related to the frequency standards, with the research and development of these concepts, we should take the regular characteristics between frequency signals as another important consideration factor. Therefore this technique can be used to simply the structure of frequency standards.

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