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A NEW PHASE NOISE DETECTION METHOD

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Abstract: *Phase noise is one of the most important parameters in many oscillators. Detecting accurately phase noise for oscillators has importance significance. In this paper, based on correlation operation to detect phase noise for oscillators was proposed. This method not only can save a high precision reference oscillator, but also can detect accurately the phase noise of measured oscillator in theory. Detected phase noise of oscillators using this method has very strong utility value.*
Keywords: *Oscillator, Phase Noise, Detection, Correlation Operation.*

1. Introduction

A variety of oscillators are widely used with the rapid development of information technology. Most importantly, the specifications of oscillator are critical in improving the performance of whole equipments and systems. The specification of phase noise is the most important one among all the parameters of oscillator [1-3]. Phase noise and short term frequency stability are two representations of the same physical phenomenon. Short term frequency stability is a time domain description. Phase noise is a frequency domain description which describes stochastic fluctuation of oscillator phase [4]. Phase noise is defined as the ratio of the single side-band power at a frequency offset of from the carrier with a measurement bandwidth of 1Hz to the carrier power [5-6]. If an emission excitation signal or a local oscillation signal contained phase noise, noise will likewise appear in receiving end in signal. Thereby, Signal-to-noise ratio will be descended and error rate will be worsened as a result of the unwanted carrier modulation. Therefore, it is valuable to investigate the phase noise's detection of oscillator.

The existing main detection methods of phase noise are as following, frequency heterodyne method, direct detection method, frequency discriminator method and phase discriminator method [7-9]. Frequency heterodyne method for time domain measurement, the other method is generally used for frequency domain measurement. As for the direct detection method and frequency discriminator method, because of its inherent defects, that make phase discriminator method as a relatively better method is widely used in phase noise detection in frequency domain. But because of this method need high precision oscillator as a reference source, improved the detection cost as a result. This paper presents a method to directly measure the phase noise by using correlation operation. This method not only can save a high precision reference oscillator, but also can detect accurately the phase noise of measured oscillator in theory.

2. Measurement Principle of Phase Discriminator Method

Phase discriminator method is also called the two-source method. The measurement principle is shown in Figure 1.

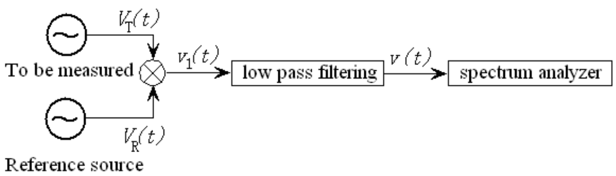

Figure 1. The measurement principle of phase discriminator method

To be measured' signal output and reference source' signal output are expressed as

$$v_T(t) = V_T \cdot \cos[\omega_T t + \Phi_T(t)] \qquad (1)$$

$$v_R(t) = V_R \cdot \cos[\omega_R t + \Phi_R(t)] \qquad (2)$$

The mixer's output voltage $v_1(t)$ is the product of two input voltages, so it is

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$$v_1(t) = v_T(t) \cdot v_R(t) \\ = \frac{1}{2} V_R \cdot V_T \cos[(\omega_R - \omega_T)t + \Phi_R(t) - \Phi_T(t)] + \\ \frac{1}{2} V_R \cdot V_T \cos[(\omega_R + \omega_T)t + \Phi_R(t) + \Phi_T(t)] \quad (3)$$

By using low pass filtering, we have

$$v(t) = \frac{1}{2} V_R \cdot V_T \cos[(\omega_R - \omega_T)t + \Phi_R(t) - \Phi_T(t)] \quad (4)$$

Let

$$K_\Phi = \frac{1}{2} V_R \cdot V_T ; \Delta\Phi'(t) = \Phi_R(t) - \Phi_T(t)$$

Mixer as a phase detector, the input signal should be satisfied as:

1) The frequency is equal,

2) The phase is quadrature.

That is

$$\omega_R = \omega_T ; \Delta\Phi'(t) = (2k+1)\frac{\pi}{2} + \Delta\Phi(t) \quad (5)$$

So

$$v(t) = K_\Phi \sin[\Delta\Phi(t)] \quad (6)$$

When $\Delta\Phi(t) << 1rad$, we have

$$v(t) \approx K_\Phi \Delta\Phi(t) \quad (7)$$

So, by using Fourier transform, we have

$$\Delta V(f) = K_\Phi \Delta\Phi(f) \quad (8)$$

This is the phase noise measurement's process of phase discriminator method.

3. New Measurement Method Based on Correlation Operation

The measurement principle based on correlation operation is shown in Figure 2.

Suppose produced phase noise of measured oscillator in two channels respectively are

$$P_1(t) = x_1(t) + f(t) \quad (9)$$

$$P_2(t) = x_2(t) + f(t+\varphi) \quad (10)$$

Where $x_1(t)$, $x_2(t)$ are produced phase noise in two phase detection channels, $f(t)$ is measured oscillator's phase noise, φ is phase difference of measured oscillator's phase noise in two phase detection channels, so the correlation function of $P_1(t)$ and $P_2(t)$ is

$$R_{12}(\tau) = \lim_{T\to\infty} \frac{1}{2T} \int_{-T}^{T} P_1(t) P_2(t+\tau) dt \\ = \lim_{T\to\infty} \frac{1}{2T} \int_{-T}^{T} [x_1(t) + f(t)] \\ \cdot [x_2(t+\tau) + f(t+\tau+\varphi)] dt \\ = \lim_{T\to\infty} \frac{1}{2T} \int_{-T}^{T} [x_1(t) x_2(t+\tau) + x_1(t) f(t+\tau+\varphi) \\ + f(t) x_2(t+\tau) + f(t) f(t+\tau+\varphi)] dt \quad (11)$$

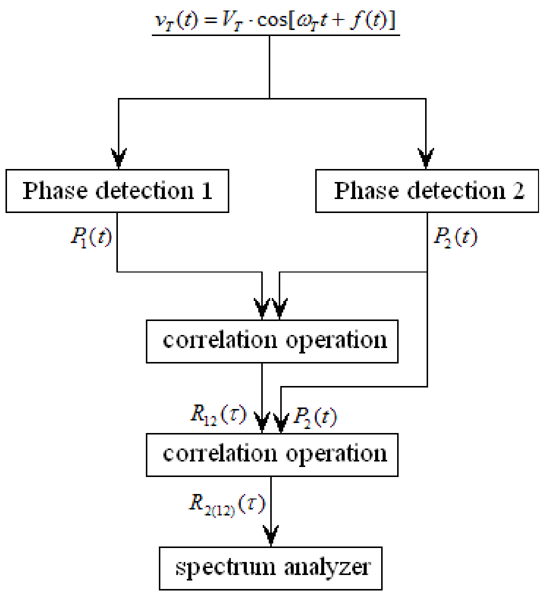

Figure 2. The measurement principle based on correlation operation

Because two phase detection channels is totally independent each other, their phase noise is uncorrelated, measured oscillator's phase noise is also independent with produced phase noise in two phase detection channels, so their cross-correlation function value is zero. We have

$$\lim_{T\to\infty} \frac{1}{2T} \int_{-T}^{T} x_1(t) x_2(t+\tau) dt = 0 \quad (12)$$

$$\lim_{T\to\infty} \frac{1}{2T} \int_{-T}^{T} x_1(t) f(t+\tau+\varphi) dt = 0 \quad (13)$$

$$\lim_{T\to\infty} \frac{1}{2T} \int_{-T}^{T} f(t) x_2(t+\tau) dt = 0 \quad (14)$$

equation(11) can be simplified as

$$R_{12}(\tau) = \lim_{T\to\infty} \frac{1}{2T} \int_{-T}^{T} f(t) f(t+\tau+\varphi) dt \quad (15)$$

Because oscillator's phase noise can be expressed as a complex periodic function form as follows

$$f(t) = \sum_{i=1}^{n} A_i \sin(\omega_i t + \theta_i) \quad (16)$$

Substitute equation(16) into equation(15), we have

$$R_{12}(\tau) = \lim_{T\to\infty} \frac{1}{2T} \int_{-T}^{T} (\sum_{i=1}^{n} A_i \sin(\omega_i t + \theta_i)$$
$$\sum_{i=1}^{n} A_i \sin(\omega_i t + \omega_i \tau + \theta_i + \varphi))dt \quad 17)$$
$$= \frac{1}{2}\sum_{i=1}^{n} A_i^2 \cos(\omega_i \tau + \varphi)$$

and then, make a cross-correlation operation for $R_{12}(\tau)$ and $P_2(t)$ in phase detection channel 2, we have

$$R_{2(12)}(\tau) = \lim_{T\to\infty} \frac{1}{2T} \int_{-T}^{T} P_2(t) R_{12}(t+\tau) dt$$
$$= \lim_{T\to\infty} \frac{1}{2T} \int_{-T}^{T} [x_2(t) + f(t+\varphi)]$$
$$\cdot R_{12}(t+\tau)dt$$
$$= \lim_{T\to\infty} \frac{1}{2T} \int_{-T}^{T} [x_2(t) R_{12}(t+\tau)$$
$$+ f(t+\varphi) R_{12}(t+\tau)]dt \quad (18)$$
$$= \lim_{T\to\infty} \frac{1}{2T} \int_{-T}^{T} [\sum_{i=1}^{n} A_i \sin(\omega_i t + \theta_i + \varphi)$$
$$\cdot \frac{1}{2}\sum_{i=1}^{n} A_i^2 \cos(\omega_i t + \omega_i \tau + \varphi)]dt$$
$$= \frac{1}{4}\sum_{i=1}^{n} A_i^3 \sin(\theta_i - \omega_i \tau)$$

By a trigonometric transform for equation (18), we have

$$R_{2(12)}(\tau) = \frac{1}{4}\sum_{i=1}^{n} A_i^3 \sin(\omega_i t + \pi - \theta_i) \quad (19)$$

Contrast equation (19) and equation(16), it shows that, through detected phase of two phase detection channels, and then make two cross-correlation operations, which can obtain all information of measured oscillator's phase noise, make a fourier transform for equation (19), we can know the each harmonic's amplitude and phase of measured oscillator's phase noise. So, using this correlation operation method, we can detect accurately the phase noise of measured oscillator without a high precision reference oscillator accurately.

4. Conclusions

By using the oscillation signal with phase noise through two phase detections, due to two phase detection channels are totally independent each other, their phase noise are uncorrelated, measured oscillator's phase noise are also independent with produced phase noise in two phase detection channels, so their cross-correlation function value are zero, then to do two correlation operations, finally to do Fourier transform. We finally can obtain all information of the measured phase noise of oscillator. This method can detect accurately the phase noise of measured oscillator without a high precision reference oscillator. So, this method not only can save a high precision reference oscillator, but also can detect accurately the phase noise of measured oscillator in theory. Detected phase noise of oscillators using this method has very strong utility value.

5. References

[1] G. F. Yan and X. H. Huang, "Research on Phase noise of Oscillators: A Survey", *Journal of Astronautic Metrology and Measurement*, vol. 29, no. 4, pp. 74-78, August 2009.
[2] G. F. Yan and X. H. Huang, "Chaos on Phase Noise of Van Der Pol Oscillator", *TELKOMNIK*, vol. 8, no. 3, pp. 301-308, December 2010.
[3] N. Prapto, K. P.Ramesh, K. Haruichi and Y. Keiji, "A 59 GHz Low Power and Wide Tuning Range CMOS Currentcontrolled Ring Oscillator", *International Journal of Electrical and Computer Engineering*, vol. 2, no 3, pp. 293-300, June 2012.
[4] W. P. Robins, "Phase Noise in Signal Sources(Theory and Applications)". Peter Peregrinus, London, UK, 1982.
[5] D. L. Yan, "Development of Phase Noise Measurement Technology", *Journal of Astronautic Metrology and Measurement*, vol. 26, no. 5, pp. 59-61, October 2006.
[6] Y. T. Wang, W. Lin and S. Z. Huang, "Theory and technology of phase noise measuring in spectrum analyzer", *Electronic Test*, vol. 20, no. 12, pp. 11-15, December 2008.
[7] Z. Q. XI, "Research on a High Precision Phase Noise Measurement Method", *Science & Technology Information*, vol. 4, no. 25, pp. 89-90, December 2009.
[8] Y. Y. Liu, S. W. Xu and Z. Q. Xuan, "Measurement for phase noise using spectrum analyzer and the analysis of its measurement uncertainty", *Electronic Measurement Technology*, vol. 29, no. 5, pp. 42-45, October 2006.
[9] I. Zamek and S. Zamek, "Crystal oscillators jitter measurements and its estimation of phase noise", *Frequency Control Symposium and PDA Exhibition Jointly with the 17th European Frequency and Time Forum*, Tempa, Florida, 2003, pp. 547–555.

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