Analysis and Conversion of Phase Noise and Timing Jitter in Crystal Oscillator

Yan WANG[1, a]

[1]School of Electrical Engineering and Information, Southwest Petroleum University, Chengdu, 610500, China

[a]email: wangyan80410468@163.com

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Abstract. According to the analysis of phase noise and timing jitter in oscillators, a simple method of converting phase noise to timing jitter is presented and calculation examples are given. The result shows that the calculation timing jitter and measured value are very close. Therefore the timing jitter can be obtained by phase noise spectrum with some approximations.

Introduction

Low phase noise frequency source is the essential part in almost all electronic systems. Crystal oscillators as the key components of producing time and frequency reference need high stability. Phase noise and timing jitter of crystal oscillators are very important characteristics to limit the performance of circuit and system in frequency and time domains separately [1][2][3]. Therefore, requirement indexes of jitter and phase noise are needed in the practical systems.

Descriptions of phase noise and timing jitter are briefly presented and their relationship between them is illustrated in this paper. Then the conversion method from phase noise to timing jitter is given and the timing jitter is obtained by calculation from phase noise spectrum. The piecewise linearization method was used in the calculation.

Analysis of Phase Noise and Jitter

Phase noise and jitter of oscillators are related quantities describing the same phenomenon. Phase noise is in frequency domain and jitter is in time domain.

Phase noise of oscillators in frequency domain is the noise sideband distributed on both sides of the carrier signal. If a signal with noise sideband is as frequency reference, phase noise and signal will appear in demodulation terminals together within the process of demodulation, this phenomenon will reduce the signal to noise ratio. Phase noise spectrum is defined as:

$$L\{\Delta\omega\} = 10\log[\frac{P_{sideband}(\omega_0 + \Delta\omega, 1\text{Hz})}{P_{carrier}}] \tag{1}$$

Where the numerator is single sideband power when frequency offset from carrier is $\Delta\omega$ and measurement bandwidth is 1Hz, the denominator is the total carrier power.

Timing jitter is produced when one of the rising and falling edges of the clock deviates from its ideal location. Jitter accumulated in N clock cycles presents square root of N cycle values deviations from the average value. Jitter can be measured by the high precision digital oscilloscope. Because of the limitation of measured equipment of jitter, it is much easier to measure phase noise than to measure timing jitter [4][5][6]. Therefore, conversion calculation from phase noise to timing jitter is concerned.

As we all known, a sine clock signal with phase noise can be described as:

$$V(t) = V_0\sin[2\pi f_0 t + \theta(t)] = V_0\sin\{2\pi f_0[t + \frac{\theta(t)}{2\pi f_0}]\} \tag{2}$$

Where f_0 is the central frequency.

According to equation (2), the timing jitter is:

$$J = \frac{\theta(t)}{2\pi f_0} \tag{3}$$

Associated the phase noise definition and equation (3), timing jitter can be written as equation (4) [7][8][9][10]:

$$\text{RMS } J = \frac{1}{2\pi f_0}\sqrt{2[\int_{f_A}^{f_B} 10^{\frac{L(f)}{10}} df]} \tag{4}$$

Where f_0 is the central frequency, RMS is root-mean-square, *L(f)* is phase noise spectrum and it often be obtained by piecewise linearization method, then the integration can be simplified.

Conversion and Calculation results

The equation (4) was calculated in Matlab. The phase noise curve used in this calculation is from a high performance oscillator made by SiTime Company that the center frequency is 156.25MHz and measured time jitter is 0.63ps. The phase noise curve shown in Fig.1 is derived by approximation.

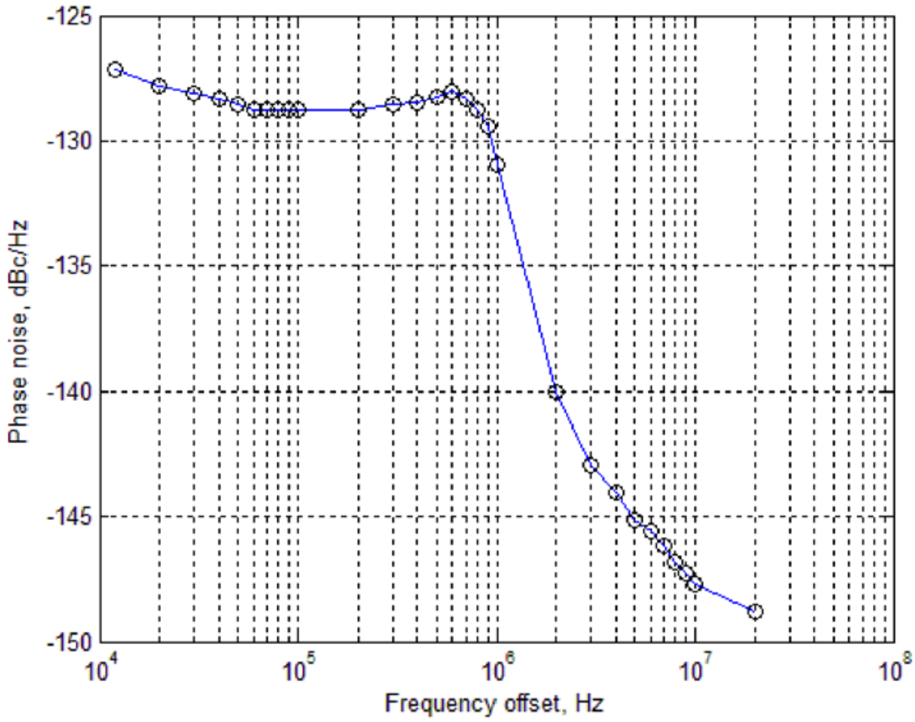

Fig.1. The phase noise curve for calculation

Through piecewise approximation calculation and equation (4), the measured timing jitter with phase noise in Fig.1 is 0.6778ps, there exists about 7.59% difference between measured timing jitter and calculated one. It is because the data points we choose in the calculation is not enough. The difference will be reduced if more data points are chosen.

If the simulation phase noise curve used in the calculated is from a Colpitts crystal oscillator simulation result shown in Fig.2. According to equation (4), the timing jitter is calculated by Matlab and the result is 0.1415ps.

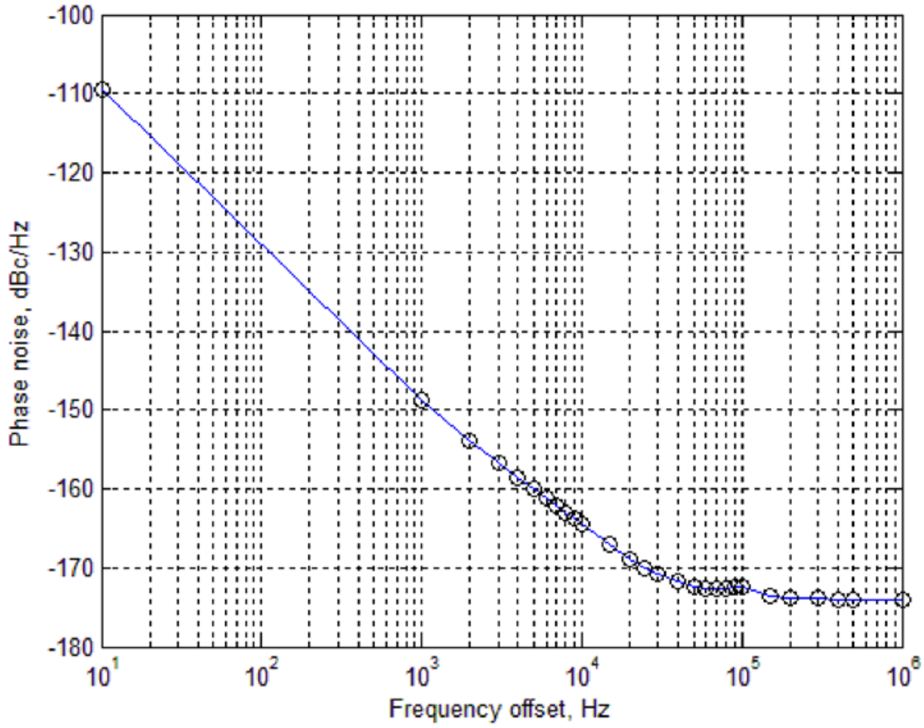

Fig.2. The phase noise curve of a Colpitts crystal oscillator

Conclusion

This paper presents the mathematical relationship between the jitter in time domain and phase noise in frequency domain. Based on the mathematical relationship, the estimation value of jitter from phase noise spectrum is obtained. The result shows that the jitter can be derived from phase noise spectrum through calculation, and the estimated value and measured value is very close, so it is feasible to obtain timing jitter without measurement but by calculation.

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