Signal Quality and Reference Signal Sources Required for Communications Systems (2)

Review of Phase Noise Properties Attributable to Oscillator Structure

[Preface]

Communication protocols require signals handled by high-speed communications transmission networks to achieve signal quality performance such as bit error rate (BER) (refers to the bit error rate calculated by dividing the number of error bits among data received by the recipient during transmission by the total number of data bits transmitted). Accordingly, system designers are tasked with creating designs for ASIC, board layouts, and component changes etc. that do not result in the deterioration of signal quality.
The noise and jitter performance of the reference signal source itself is a vital parameter affecting the ability to maintain a high-quality signal. As such, the previous White Paper introduced key oscillator specifications necessary to achieve the signal quality required in communications systems, as well as Epson products ideal for communications equipment based on the structure and characteristics of oscillators currently on the market. In this White Paper, we take a closer look at the phase noise properties resulting from the structural differences of oscillators on the market.

[Structures/characteristics of oscillators (reference signal sources) on the market]

The structures (types) of oscillators used in the market are indicated in Figure 1 and their respective characteristics are indicated in Table 1.

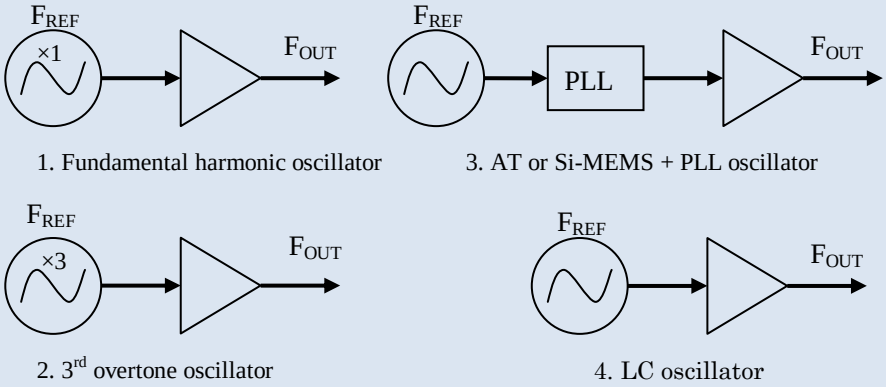

Fig. 1 Oscillator Structure

Table 1 – Characteristics resulting from oscillator structural differences

Oscillator structure (type)	Characteristics
Fundamental harmonic oscillator	Superior resistance to noise, jitter, and spurious. Simple circuit structure and low power consumption.
Overtone oscillator	Superior resistance to noise, jitter, and spurious but the circuit design (structure) is complicated and difficult, requiring a higher power consumption and capacity ratio, which makes it more difficult to maintain frequency variable width.
PLL oscillator	PLL allows for easy setting of desired frequencies but the circuit structure is complicated so the power consumption is large. This also negatively impacts noise and jitter performance.
LC oscillator	Easily structured with L and C to attain broad output amplitude but the power consumption is large and noise is significant due to the poor frequency stability and aging properties of the material.

As indicated in the above characteristics, attainable properties will vary depending on the structure of the oscillator. This White Paper provides detailed explanations of the characteristics and tendencies of phase noise properties seen in fundamental harmonic oscillators, PLL oscillators, and LC oscillators from the perspective of noise and jitter properties, which greatly impact signal quality in communications systems.

[Phase Noise Property Slope Characteristics]

As indicated in Figure 2, phase noise properties are represented by the image of a slope. These slopes are largely divided into five types, with each slope demonstrating the following types of characteristics. A simple explanation for each of these characteristics is provided below.

1) Random walk frequency modulation (RWFM) has a slope that is inversely proportionate to the 4th power of the offset frequency and primarily indicates the effect of frequency fluctuations in the oscillating source (phase variation is converted into frequency variation).
2) Flicker frequency modulation (FFM) has a slope that is inversely proportionate to the 3rd power of the offset frequency and primarily indicates the effect of flicker noise from the oscillating source.
3) White frequency modulation (WFM) has a slope that is inversely proportionate to the 2nd power of the offset frequency and primarily indicates the effect of the circuit-side Q value.
4) Flicker phase modulation (FPM) has a slope that is inversely proportionate to the offset frequency and, similar to FFM, indicates the effect of noise resulting from the physical oscillation side (circuit side).
5) White phase modulation (WPM) has a constant slope that bears no correlation with the offset frequency and primarily indicates the impact of circuit noise (component heat noise) and the oscillation signal S/N ratio.

From this, we see that the slope images of phase noise properties can be largely categorized as RWFM and FFM being impacted by the oscillating source while WFM, FPM, and WPM are impacted by the circuit structure.

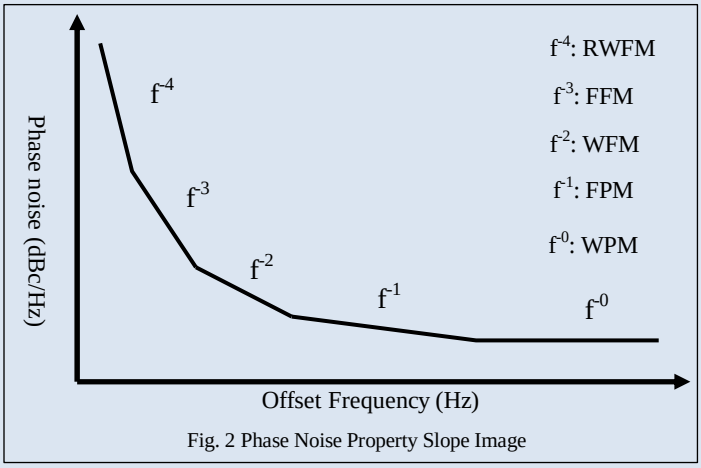

Fig. 2 Phase Noise Property Slope Image

[Calculating Phase Jitter Based on Phase Noise Properties]

As was introduced in the Technical Notes back “Jitter and Phase Noise,” phase jitter can be calculated using the integral value of the offset frequency range specific to the phase noise properties.

Communications system performance is affected by the volume of phase jitter within the communications loop bandwidth. The volume of phase jitter (SONET/SDH standards) at 12k-20MHz, the equivalent bandwidth for communications loops in the majority of communication systems, is currently one of the major indicators of phase jitter. Figure 3 shows the correlation between phase noise properties and phase jitter.

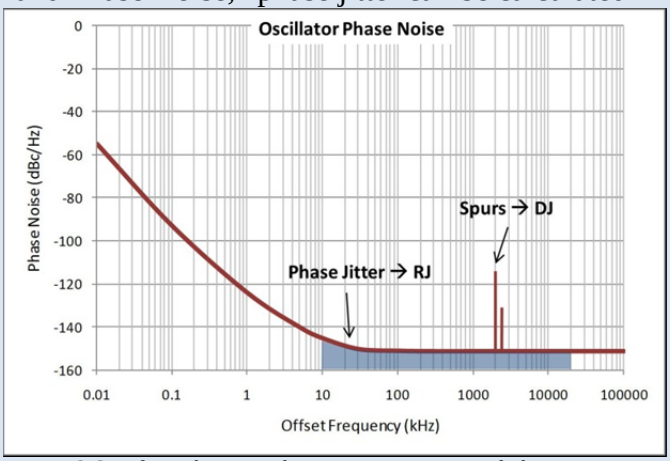

Fig. 3 Correlation between Phase Noise Properties and Phase Jitter

Total jitter (TJ) refers to the sum of deterministic jitter (DJ) and random jitter (RJ). In systems with phase noise properties like those seen in Figure 3, the sum of the integral value for the 12k – 20MHz range representing the communications loop bandwidth (RJ) (blue portion in Figure 3) and the integral value for spurious (DJ) represents the total phase jitter.

[Phase Noise Properties Attributable to Oscillator Structural Differences]

To help readers understand the characteristics of phase noise properties attributable to oscillator structural differences, the structures introduced in Figure 1 are used to explain tendencies in phase noise properties for three types of oscillators: the fundamental harmonic oscillator, which uses a crystal unit as the oscillating source, the Si-MEMS oscillator, which uses a PLL circuit design and an Si resonator as the oscillating source, and the LC oscillator, which uses LC oscillation as the oscillating source. Phase noise property images of each oscillating source for the crystal, Si resonator, and LC oscillation are indicated respectively in Figure 4.

First, the differences in slope gradient in the carrier vicinity (low band side) depend greatly on the Q value of the oscillating source. Crystal, which has a particularly high Q value, has low phase noise properties up to an offset frequency of 100kHz while with LC oscillation, which has an extremely low Q value that is not exceeding 100, phase noise properties in the carrier vicinity (low band side) tend to worsen. In contrast, regardless of the oscillating source the high band side of the slope is largely influenced by noise emitted from the circuits. As such, floor level tends to be lower when the signal elements are larger than the noise elements. LC oscillation in particular has a large output amplitude and significant signal strength, thus phase noise tends to be smaller on the high band side. In comparison, there are limits to the amount of power that can be applied to Si resonators, resulting in small output amplitude and weaker signal strength that makes them less ideal on the high band side when compared to crystal or LC oscillation. Of course, another method of reducing phase noise on the high band side would be to increase the power consumption, thereby increasing signal strength and lowering the floor level. This method creates the mutual trade-off of improving phase noise versus maintaining low power consumption.

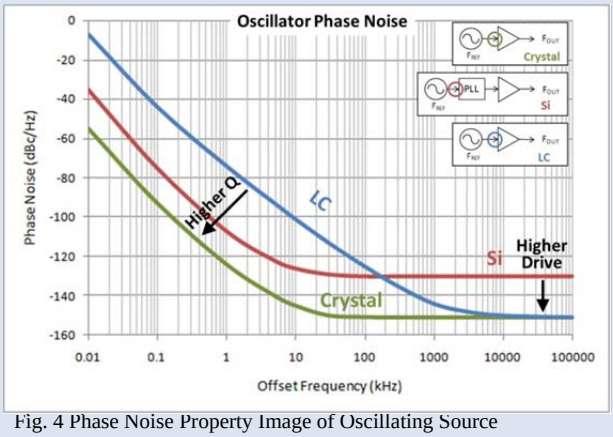

Fig. 4 Phase Noise Property Image of Oscillating Source
(Phase noise property image of portions encircled in green, red, or blue in the oscillator block image to the above right.)

Thus far, we have examined an image of phase noise properties related to oscillating source. With Si resonators, fluctuation caused by the natural temperature properties of the crystal has a significant influence, so structuring Si resonator as an oscillator requires that this temperature dependence be compensated in order to secure stability. As such, PLL is used as the compensation circuit in many oscillators. Below, we use Figure 5 to explain the image of phase noise properties for Si resonator oscillating source passed through a PLL circuit.

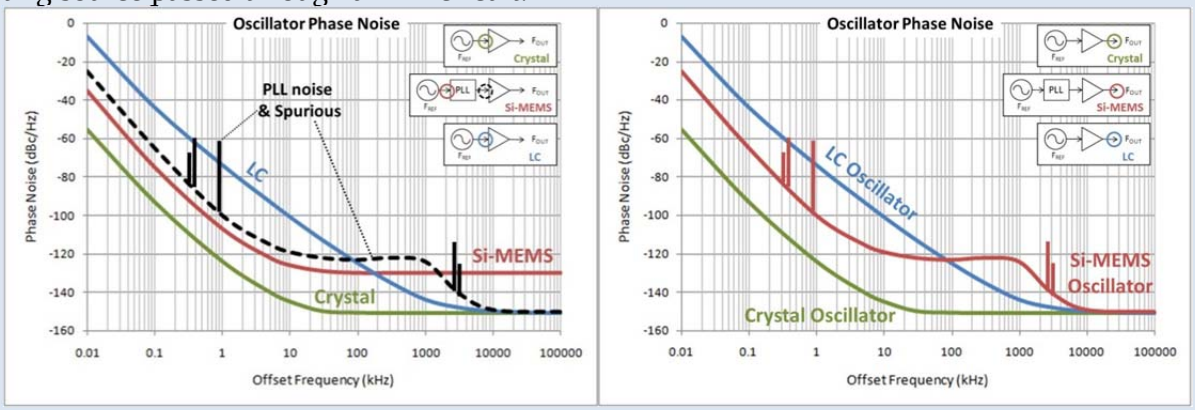

Fig. 5 PLL Circuit Phase Noise Property Image (left) and Phase Noise Property Tendencies based on Oscillator Structural Differences (right)

As shown in Figure 5 (left), oscillators using PLL circuits tend to experience dips in a portion of the phase noise curve. This is the result of the design comprising a PLL that uses an oscillating source to lock the voltage-controlled oscillator (VCO) and output a multiplied frequency. As a result, the phase noise properties of oscillators using a PLL circuit are subject to the influences of two elements: the VCO and the PLL. In general, these properties manifest because a VCO demonstrates phase noise properties that are inferior to crystal oscillating source and, with PLL circuits, the phase noise properties of the VCO appear on the high band side. Furthermore, because the phase noise level on the low band side varies depending on the number of multipliers, phase noise properties tend to deteriorate as the number of multipliers increases and deterioration also will result from the spurious generated by the PLL and the multiplier. Also, as properties on the high band side are determined by the circuit output amplitude, all of these properties are constant regardless of the oscillating source.
Lastly, the tendencies of phase noise properties in relation to output for the three types of oscillators, the fundamental harmonic oscillator, which uses a crystal unit as the oscillating source, the Si-MEMS oscillator, which uses a PLL circuit design and an Si resonator as the oscillating source, and the LC oscillator, which uses LC oscillation as the oscillating source, are shown on the right side of Figure 5.

[Oscillator Structure Required for High-Speed Communication Systems Based on Phase Noise Properties]

We have explained that tendencies in phase noise properties change based on oscillator structural differences. When a designer designs a system, the selection of electric components, board layout, and ASIC design are determined based on whether priority is placed on carrier vicinity (low band side) noise properties (Figure 6, left) or the equivalent phase jitter volume (Figure 6, right) within the communications loop bandwidth (12k – 20MHz) used in SONET/SDH. When designing a high-speed communications systems, it is believed that the use of fundamental harmonic crystal oscillators, which provide low phase jitter properties and superior frequency stability, will achieve greater overall stability as a communication system compared to the use of products with significant risk elements such as an Si-MEMS oscillator (risk of phase noise curve dipping unique to PLL circuits and spurious) or LC oscillators, which demonstrate poor frequency stability.

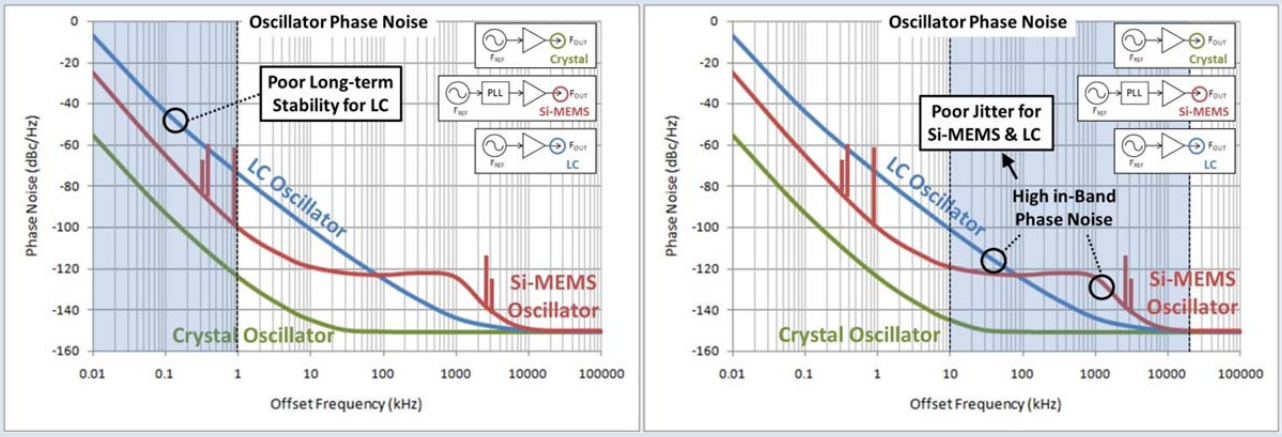

Fig. 6 Comparison of Carrier Vicinity (Low Band Side) Properties (left) and Floor Level (High Band Side) Properties (right)

Epson crystal-based oscillators are unique for their stable phase noise properties from the carrier vicinity (low band side) to the floor level (high band side) and our fundamental harmonic oscillation employs a simple circuit structure that enables low power consumption. Fundamental harmonic oscillators using a crystal as the oscillating source will become a vital component in the system structures of communication systems that will continue to achieve greater speed performance. At Epson, we will continue our development of products that achieve the levels of performance required by our customers.