Signal Quality and Reference Signal Sources Required for Communications Systems (1)

Key Specifications for Oscillators Used as Reference Signal Sources and Introduction of Related Products

[Preface]

The world of communication networks is similar to a tree, expanding from core and metro networks to mobile backhaul, access, and enterprise networks (LAN/SAN). Technical standards have been outlined for each type of communication. The expansion of high-speed communication devices and video streaming seen in recent years has resulted in continues increase in the amount of traffic flowing along the internet backbone. In response to speed increases and data volume, we are seeing the upgrading and expansion of the communications infrastructure equipment. The communication protocols that facilitate this type of high-speed data communication require performance in transmission channels and 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). In particular, BER Value is defined by signal quality, noise and jitter properties of the signal.

These White papers explain the key specifications of oscillators based on signal quality required for communications equipment. Furthermore, we introduce structures and properties of oscillators on the market as well as Epson products appropriate for communications equipment.

[Structure of High-Speed Communications Systems]

Figure 1 shows a typical communications system (transmission channel) where data forwarding between two transceivers is mediated by multiple protocols (PCI, SATA, 10GbE, etc.). In this type of system, oscillators are used to generate the reference clocks. Generally, data is serialized on the sender side by the reference signal to account for the reference signal being oscillated at a frequency that is lower than the data rate. As such, the transmitter's internal PLL (Phase Locked Loop) is used to multiply the reference signal to the desired frequency and the data is transmitted. Conversely, on the recipient end, the PLL-based CDR (Clock Data Recovery) is used to regenerate the reference signal from the transmitted data stream, and then the regenerated reference signal is used to reconstruct the data. In some high-end systems, the recipient end has an embedded reference signal that is used to data reconstruction. With this kind of data transmission, signal translation and regeneration are conducted perpetually and with high-speed communications, the recipient end must accurately identify sent data as 0's and 1's. As such, how to limit the degradation level (jitter, noise) of the actual signal, raise the signal quality as well as how to effectively design the transmission channel ASIC become vital issues.

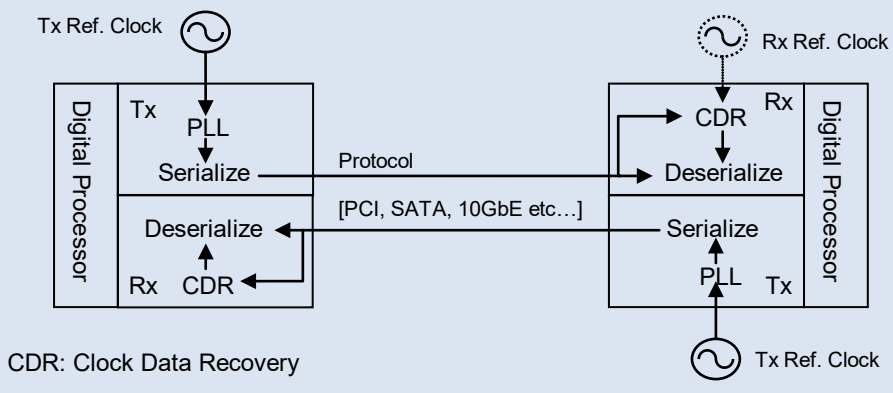

Fig. 1 Communications System Transmission Channel Structure

[Signal Quality Evaluation Methods]

Eye diagrams are often used as a method for evaluating signal quality in communication systems. These diagrams use an oscilloscope or a similar measurement device to take multiple samples of the high-speed digital signal waveform. These waveforms are then layered on top of each other to create a graphical representation. The name "eye diagram" comes from the visual appearance of layered waveforms, which resemble an eye.

As an example, we shall look at when 10GbE is used as the transmission channel communication protocol. With this system, the time (length) required to forward a 10Gbps signal is equivalent to a 100psec per bit signal. To evaluate signal quality, the signals are repeated every 100psec to gain an eye diagram. If, for example, we assume that the reference signal is pure and that the transmission channels ASIC has been designed well, then we will observe well-aligned waveform as shown to the left in Figure 2. Conversely, in cases of signal loss such as insufficient band in the transmission channel caused by a reference signal with significant noise or jitter or a poorly designed ASIC, the signal waveform is unstable and layering of the waveforms results in the type of "closing eye" as shown to the right in Figure 2.

Identifying signal data as 0 or 1 relies heavily on the horizontal and vertical directions of the eye opening achieving sufficient aperture. If the eye opening is contracted as a result of noise or jitter, recipient end signal data identification is ambiguous and results in a higher BER. At present, almost all communication systems require BER of at least $1x10^{-12}$. This means that for each data transfer bit, one error against 10^{12} data amount is tolerated.

As seen above, eye diagrams provide a wealth of information related to signal quality, such as noise, jitter, and insufficient band.

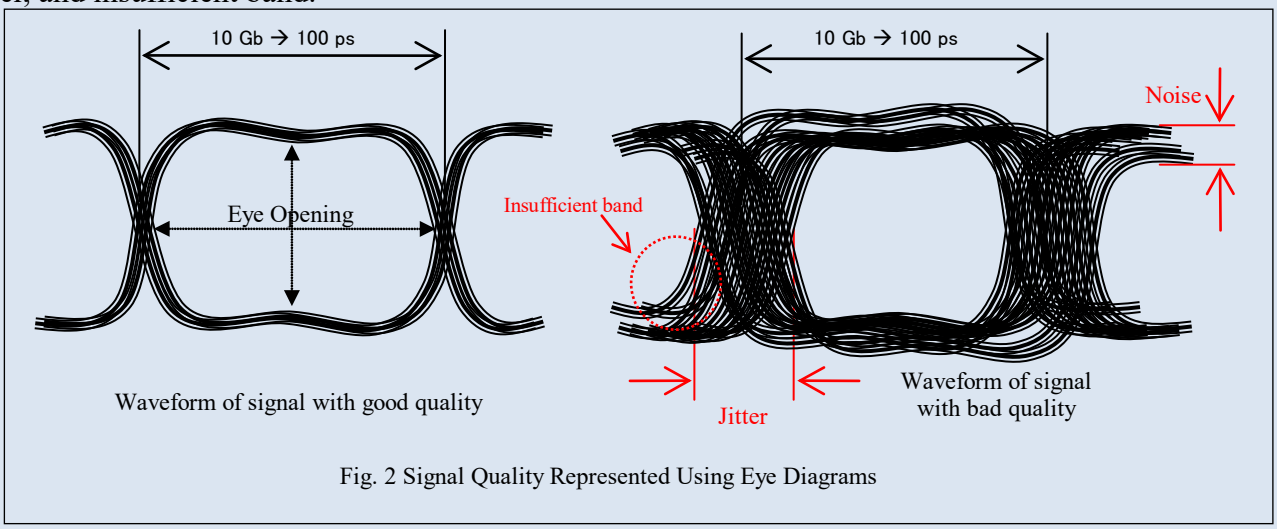

Fig. 2 Signal Quality Represented Using Eye Diagrams

[Structural Elements of Jitter]

The structural elements of jitter present in communication systems are shown in Figure 3.

TJ (Total Jitter) represents the summation of DJ (Deterministic Jitter) and RJ (Random Jitter).

DJ (Deterministic Jitter) refers to jitter induced by circuit design, electromagnetic induction, and the external environment. Characteristics of DJ include a uniform width and a lack of dependence on time elapsed.

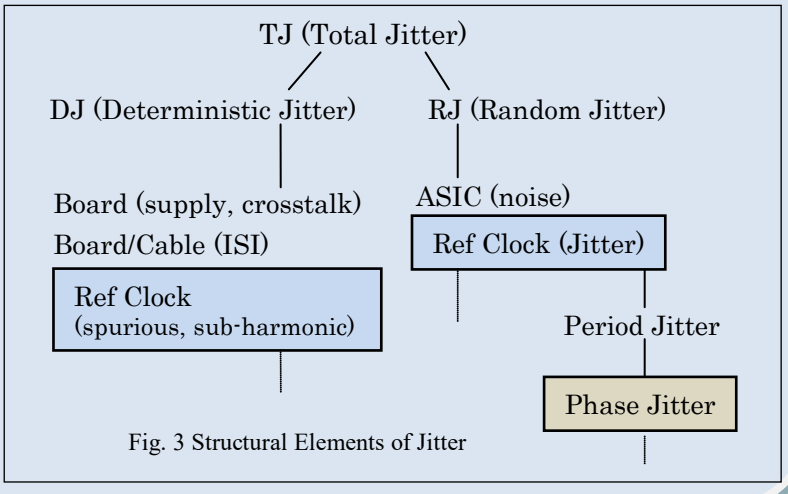

Fig. 3 Structural Elements of Jitter

Spurious and sub-harmonics are elements that contribute to DJ caused by the oscillator serving as the reference clock source.

RJ (Random Jitter), as the term implies, refers to unpredictable jitter elements and can be induced naturally based on the inherent properties of the device itself or due to the influence of heat noise, etc. RJ characteristic is growing wider as time elapses. The actual jitter of the reference signal source is the element that contributes to RJ caused by the oscillator serving as the reference clock source.

In other systems, DJ is attributes to insufficient band resulting from the impact of board PSU noise, cross talk, and cable design while RJ is attributed to ASIC noise. System designers are tasked with improving ASIC design or changing the board layout and components to reduce TJ.

[Structure and Characteristics of Oscillators (Reference Signal Sources) on the Market]

From the above section, you can see that maintaining signal quality requires the selection of a reference clock source that is not greatly impacted by noise or jitter.

Next, we review the structures (types) and characteristics of oscillators currently in the market.

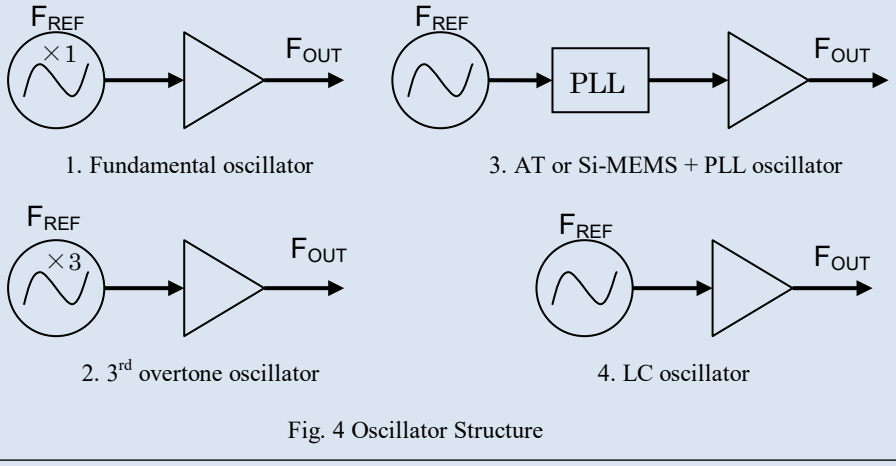

Fig. 4 Oscillator Structure

The types of oscillators currently used in the market can be divided into four major categories. Figure 4 indicates the structure of each type.

The first type is the fundamental oscillator, which is the most popular type of oscillator in the market. These oscillators demonstrate superior resistance to noise, jitter, and spurs are able to provide high precision and performance characteristics in all applications. Furthermore, fundamental oscillators employ a simple circuit structure that results in low power consumption.

The second is an oscillator that uses the 3rd overtone. Overtone oscillation employs a circuit design method in a filter circuits, this circuit is used to suppress the negative resistance of the fundamental harmonic to produce negative resistance at an order (in this case, the 3rd) of a desired frequency. This type of oscillation achieves high-frequency output that is difficult to achieve with fundamental harmonic oscillation. Also, the ability to maintain a high Q value provides favorable phase noise vicinity properties. However, circuit design (adjustment) is complicated, which results in higher power consumption. Furthermore, the capacity ratio makes it more difficult to maintain frequency variable width.

The third oscillation topology is an oscillator that uses PLL. This type of oscillators use a quartz or Si-MEM resonators, which serve as the reference signal source, as the input signal uses a PLL to generate a signal that is synchronized to that input signal, and to output the required frequency. As such, oscillators that use PLL circuit technology are superior in the sense that they achieve high frequencies as well as the convenience of being able to generate output signals at desired frequencies. However, this type of oscillator results in the complicated circuit structure, significant power consumption and can have a negative impact on noise and jitter performance. As previously introduced, with Si-MEMS oscillators, compensating the rough temperature characteristics of the Si resonator, would require the use of PLL circuit technology

(Because the compensation range is too broad and analog temperature compensation is not possible). As a result, this type is thought to present disadvantages in terms of controlling noise and jitter, which are indicators of signal quality.

Lastly, LC oscillators are similar to PLL. These products provide significant convenience. Furthermore, applying power will result in a greater amplitude and floor noise, which can be kept to a minimum. Conversely, they have problems in the low Q value of the material, which results in poor frequency stability and aging, as well as problems with noise in the vicinity of the carrier frequency.

As seen from the above, the various oscillators in the market comprise a variety of structures, making product selection based on application important. At Epson, we believe that we can contribute to maintain signal quality for our customers by providing products with oscillator performance (phase noise, phase jitter, and spurious properties) required for reference single sources.

[Introduction of Epson Oscillators with Low Phase Jitter Properties for Use in Communications Systems]

Epson positions fundamental harmonic oscillators (Type 1) as one of our primary products and we have produced a diverse lineup of products with different jitter properties for use in high-speed communication systems. Major examples of our oscillator lineup are shown in Table 1.

In general, we use crystal units as oscillating sources. However, AT cut crystals are used for frequencies up to around 70MHz and above 100MHz we offer oscillators that employ inverted-mesa AT cut (HFF: High-Frequency Fundamental) technology XO: Crystal Oscillator (SG series), VCXO (VG series).
The gap below 100 MHz is handled by dividing the inverted-mesa AT cut.
We also offer a diverse lineup to address output needs as well, including oscillators based on CMOS, LV PECL, LVDS, and HCSL output formats. All of our products retain the potential of crystal while providing product specifications to sufficiently satisfy customer expectations for signal quality in a variety of applications.

Table 1 Epson Oscillator Lineup and Phase Jitter Output

Category	Output waveform		Crystal	Model name	Size [mm]	Frequency range [MHz]	Phase jitter [ps] Typ.*1	Condition
XO (Crystal Oscillator)	CMOS		AT cut	SG2016CAN SG3225CAN SG5032CAN SG7050CAN	2.0 x 1.6 x 0.7 3.2 x 2.5 x 1.05 5.0 x 3.2 x 1.1 7.0 x 5.0 x 1.3	4 to 72 (20 周波)	0.24 0.16	40 MHz 72 MHz
				SG-210STF	2.5 x 2.0 x 0.8		0.24 0.16	40 MHz 72 MHz
XO (Crystal Oscillator)	Differential	LV-PECL	Inverted mesa AT cut (HFF)	SG2016EGN SG2016EHN	2.0 x 1.6 x 0.63	25 to 500	0.044	156.25 MHz
				SG2520EGN SG2520EHN	2.5 x 2.0 x 0.74			
		LVDS		SG2016VGN SG2016VHN	2.0 x 1.6 x 0.63		0.038	156.25 MHz
				SG2520VGN SG2520VHN	2.5 x 2.0 x 0.74			
		HCSL		SG2016HGN SG2016HHN	2.0 x 1.6 x 0.63		0.061 0.025 0.022	100 MHz 212.5 MHz 491.52 MHz
				SG2520HGN SG2520HHN	2.5 x 2.0 x 0.74			
VCXO		LV-PECL		VG3225EFN VG5032EFN VG7050EFN	3.2 x 2.5 x 1.05 5.0 x 3.2 x 1.3 7.0 x 5.0 x 1.5	25 to 500 25 to 250 25 to 250	0.055 0.022	122.88 MHz 491.52 MHz
		LVDS		VG3225VFN VG5032VFN VG7050VFN	3.2 x 2.5 x 1.05 5.0 x 3.2 x 1.3 7.0 x 5.0 x 1.5	25 to 500 25 to 250 25 to 250	0.078 0.032	122.88 MHz 491.52 MHz

*1: Phase jitter typical value (typ.) is calculated based on our measures of offset frequency at 12kHz to 20MHz at the frequency indicated in the “Condition” column.

Furthermore, refer to Epson Website for detailed product specifications.

We continue to provide products with the jitter and noise properties essential for reference signal sources.