

Jitter and Phase Noise

Jitter and Phase Noise - The Fundamentals

Preface

Data transmission speeds and volume continue to increase to support unabated growth in traffic flowing over the Internet backbone largely due to the spread of movie and other content delivery services. The need for high-speed communications infrastructure is driving strong demand for high-frequency reference signal sources that provide stable output signals. One of the indicators used to evaluate the stability of these output signal waveforms is called "jitter." When used to express the stability of a high-frequency crystal oscillator, jitter indicates a deviation or variation in the period of waveforms for a digital signal during transmission. Here the basics of jitter and phase noise are explained.

1. Jitter, a Key Indicator for Communications Equipment

Waveforms of digital signals appear as a bright line on an oscilloscope. This bright line, which should oscillate at regular intervals, sometimes appears thick. This widening of the line is evidence of jitter.

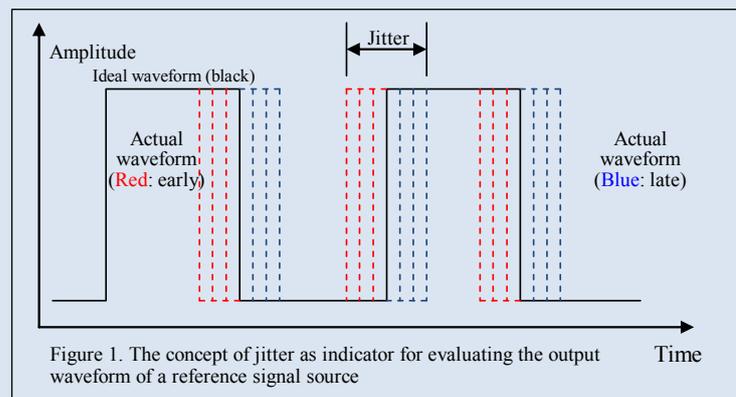


Figure 1 shows a single period, or cycle, of a signal in which multiple different periods are evident. An ideal waveform repeats an invariable cycle. Actual waveforms, however, vary in the time domain, with signal edges rising or falling earlier (red) or later (blue) than they are supposed to. Jitter is produced by things such as slight instabilities in electrical signal reading devices and interference along signal carrying pathways. If jitter is too extensive, adjacent signals interfere with one another, triggering deterioration in image and sound quality if the signals are transmitting movie or music data. Jitter is the result of time-domain fluctuations in digital signals, but jitter comes in a lot of different types. Jitter is hard to assess with a single numeric value because it changes minutely over time and because there is a variety of fluctuation patterns with respect to time.

2. Types of Jitter

There are many types of jitter, including the following:

- Period jitter (peak-to-peak)
- RMS jitter
- Random jitter
- Deterministic jitter
- Accumulated jitter (long-term jitter)

Epson measures jitter using a Wavecrest DTS-2075. The probe of the measuring instrument is placed near the output pin of the power supply, which is basically noise-free, and output impedance is set to 50 Ohms.

The horizontal axis of the graph shows one signal cycle (ps). In this measurement the variation in a cycle randomly selected 50,000 times is shown by means of a histogram. This data is for an SG-8002CA 125 MHz PCB. Ideally, there should be one peak in the 125 MHz cycle, but a variety of factors cause characteristics to change. Particularly in the case of PLLs, the tendencies indicated in the figure on the right are generally known, and how these characteristics are understood and reflected in a design become important.

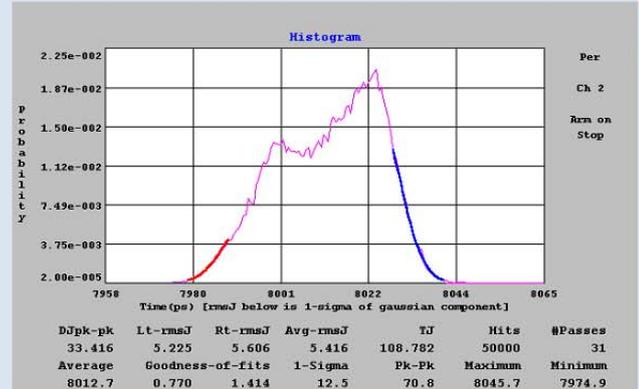


Figure 2. Histogram of data

(1) Period jitter (peak-to-peak jitter)

Period jitter is observed as variation width. Epson expresses this variation using a peak-to-peak value. In the graph above, peak-to-peak jitter is found by subtracting the minimum cycle length from the maximum cycle length.

(2) RMS jitter (1-sigma)

RMS jitter takes the standard deviation (1σ) of the above measurement results. This shows that there is a 68.26% probability that it exists within 12.5 ps.

However, peak-to-peak jitter only shows a very small portion of states (several ms) in a crystal product that is normally used for a long period of time and does not show overall jitter. RMS jitter is a valid value only for an ideal normal distribution (Gaussian distribution); its reliability for other distributions is extremely low. Given this, a technique for capturing an overall picture of jitter was conceived by dividing the histogram obtained by measurements into two components.

(3) Random jitter (RJ)

As the name suggests, random jitter is a jitter component that cannot be predicted. Random jitter can occur spontaneously as it is influenced by a device's characteristics, thermal noise, and so forth. Therefore, the histogram is considered a tool where the ideal normal distribution exists, and jitter is estimated from the curve fit of the rising and falling edges from a histogram created from actual jitter measurements. Random jitter is expressed using standard deviation, using the expressions "right RJ" and "left RJ."

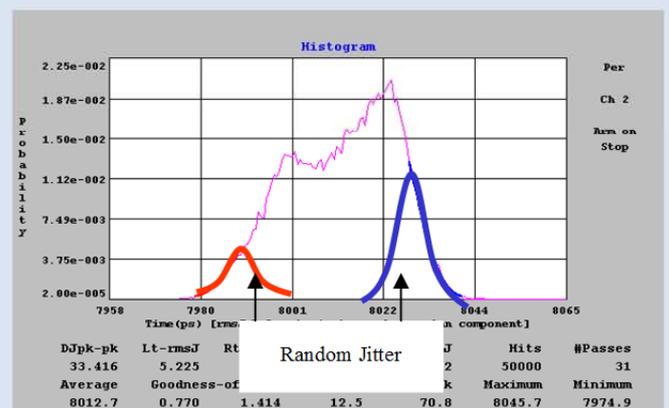


Figure 3. Explanation of random jitter

(4) Deterministic jitter (DJ)

Deterministic jitter, also known as bounded jitter, may be caused by circuit design, electromagnetic induction, or the external environment. When seen from actual measurement results, deterministic jitter is the part sandwiched between right and left random jitter.

To summarize the foregoing concepts of jitter, spontaneously induced jitter (RJ) and artificially-induced

jitter (DJ) comprise overall jitter components in a single cycle length.

The key to reducing jitter is to reduce deterministic jitter. Optimizing this component causes the gap between right and left RJ to overlap so that it can exist as an ideal normal distribution.

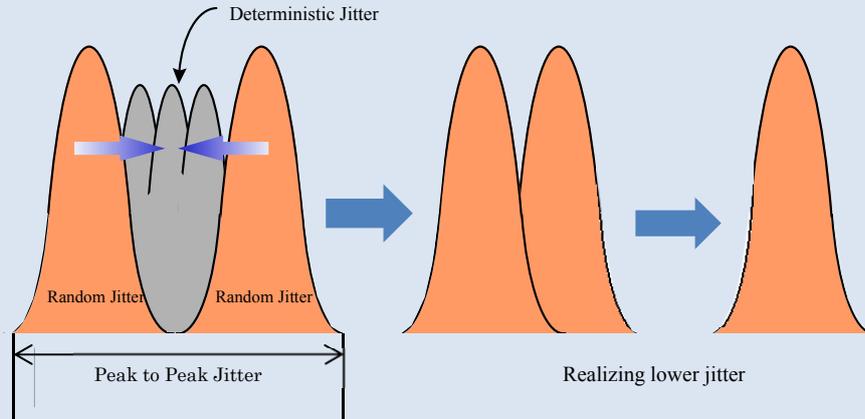


Figure 4. Explanation of deterministic jitter

(5) Accumulated jitter (long term jitter)

The types of jitter explained above were measurements of variation in reference to one cycle, or period, but there is a type of jitter that cannot be expressed in that way. That is accumulated jitter.

Accumulated jitter is observed as variation in signal waveforms across multiple consecutive cycles, not just one cycle.

The horizontal axis shows how many cycles were measured. The vertical axis shows it as 1-sigma for each respective cycle. Analyzing this jitter enables you to see the behavior of jitter that has consecutive cycles.

Jitter for accumulated cycles shows a tendency for 1-sigma to converge from a certain cycle. This enables one to determine the PLL circuit bandwidth and transient response characteristics.

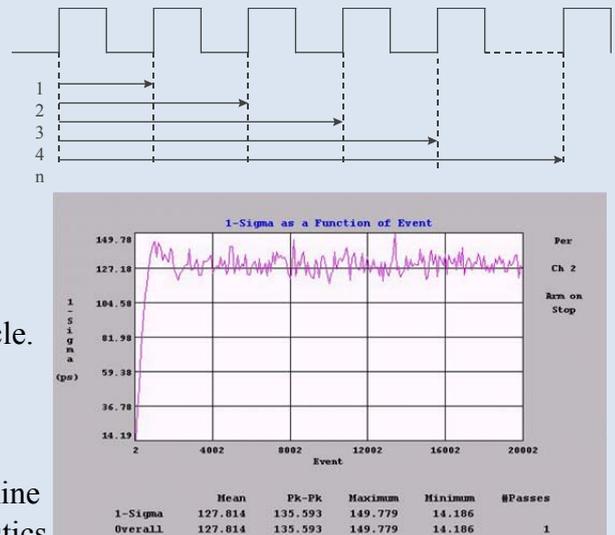


Figure 5. Explanation of accumulated jitter

3. The relationship between oscillator output and jitter

Crystal oscillators output frequency components outside the frequencies they are designed to output. As shown in Figure 6, the frequency characteristics of signals output by a crystal oscillator contain other frequencies in the vicinity of the fundamental frequency. This is produced by phase modulation due to random signals; that is, the noise source modulates the oscillator.

Commonly called phase noise, these frequencies are almost always higher than the noise floor, appearing near the carrier frequency. When expressed as an equation, noise looks like this:

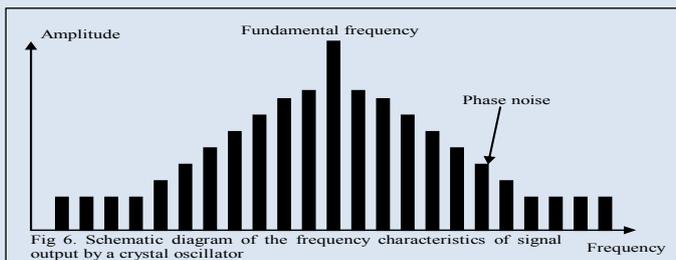


Fig 6. Schematic diagram of the frequency characteristics of signal output by a crystal oscillator

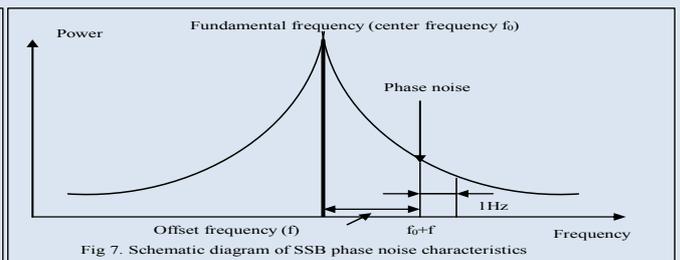


Fig 7. Schematic diagram of SSB phase noise characteristics

$$IdealsignalV(t) = A \times \sin 2\pi f_0 t \quad \dots \quad Formula(1)$$

$$ActualsignalV(t) = (A + E(t))\sin(2\pi f_0 t + \phi(t)) \quad \dots \quad Formula(2)$$

where $E(t)$ is amplitude fluctuation (AM noise), $\phi(t)$ is phase fluctuation (PM noise). $\phi(t)$ is phase noise. Phase noise is usually stated as a ratio between carrier power and noise power at an offset frequency from the carrier. All phase noise is jitter.

SSB (single sideband) phase noise $L(f)$ is usually used to express phase noise. $L(f)$ is a function of offset frequency f , the unit of which is dBc/Hz. Defined by the SSB phase noise power, it is the total power of an electrical signal in the 1 Hz bandwidth at a frequency f Hz away from the carrier (Figure 7).

Phase noise C is expressed using the following equation:

$$L(f) = (\text{Center Frequency} + f\text{Hz}) \text{Power at the 1Hz bandwidth} / \text{Total power of signal} \quad \dots \quad \text{Formula(3)}$$

Since $L(f)$ is noise, it must be converted to units of 1 Hz for comparison purposes. If A is the measurement bandwidth when phase noise is measured, then the measured phase noise is calculated by dividing it by A . For example, if phase noise was measured at -70 dBc in the 1 kHz measurement bandwidth, you would have -70dBc -30dB, yielding a result of -100 dBc/Hz. Since 1 Hz is 1/1000 of 1 kHz, the output per bandwidth would also be 1/1000 (= -30 dB). dBc/Hz is the standard unit for expressing phase noise.

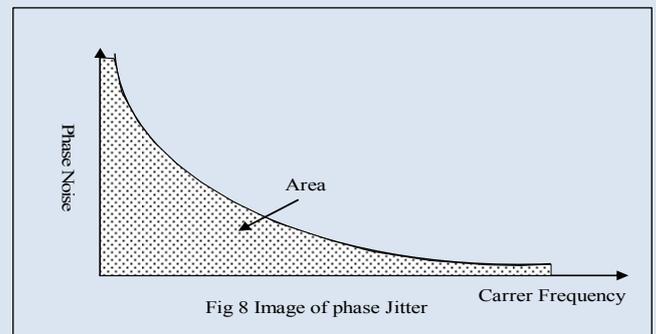
Phase noise arises from more than crystal oscillator circuits. When PLL circuits are used, phase noise is produced by circuit components, noise components, and loop characteristics, among other things. Phase noise indicates fluctuations in the phase of the signal. Therefore, when observed in the time domain, it appears as waveform jitter.

4. Phase jitter

Phase noise and jitter both indicate the stability of a signal, and are interrelated. Specifically, phase noise is the instability of a frequency expressed in the frequency domain, while jitter is fluctuation of the signal waveform in the time domain.

The graph shows offset frequency on the horizontal axis and phase noise on the vertical axis. The part that corresponds to the integral value of this phase noise (the shaded area in Figure 8) is phase jitter and corresponds to RMS jitter.

As for phase jitter, you can obtain a value for jitter that has components within a specific frequency range by calculating the integral value of a specific offset frequency range.



The market demands characteristics that are suited for a variety of applications. Going forward, Epson will continue to provide crystal devices that have the performance customers need, including the right jitter and noise characteristics.