Removing the impact of clock amplitude variations in jitter and phase noise measurement with spectrum analysers

Technical Note

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Introduction

Jitter and phase noise are critical parameters that significantly impact the performance of modern communication systems. As data rates continue to increase, the need for accurate measurement and management of these parameters becomes even more crucial. By employing advanced measurement techniques and understanding the interplay between jitter and phase noise, engineers can enhance the reliability and efficiency of high-speed communication interfaces.

The accuracy of jitter and phase noise measurements directly reflects the impact on the applications using the clocks. Inaccurate measurements can lead to over-designing the system, resulting in higher costs and power consumption. On the other hand, underestimating jitter and phase noise can cause system failures and data corruption. Spectrum analysers play a vital role in assessing the quality of clock signals by providing a frequency-domain view of time-domain signals. They allow engineers to visualise the imperfections in both phase and amplitude of signals, which are treated equally in phase noise plots. By analysing the phase noise spectrum, engineers can derive insights into the jitter characteristics of the clock signals, enabling them to make informed design decisions. One of the challenges in measuring jitter and phase noise is the impact of clock amplitude variations. These variations can obscure a signal's accurate jitter and phase noise characteristics, leading to inaccurate assessments.

This article presents a method for removing amplitude variations in jitter and phase noise measurements, representing a step in achieving more precise and reliable signal integrity assessments. By isolating the effects of jitter and phase noise from amplitude fluctuations, engineers can obtain a clearer picture of the signal's performance and optimise the system accordingly.

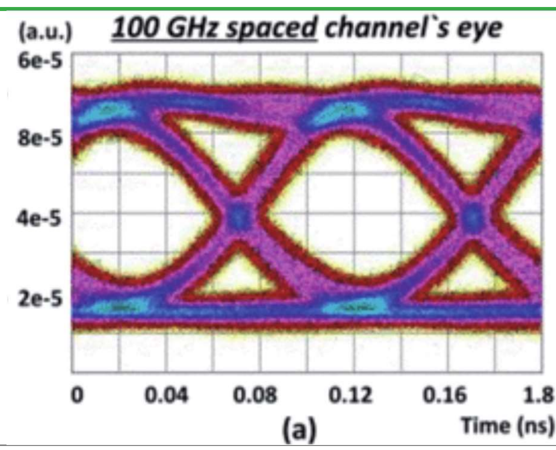
Jitter and phase noise impact on applications

ITU-T [1] defines jitter as the deviation from the true periodicity of a presumably periodic signal, often measured against a reference clock signal. Deviation frequencies below 10 Hz are classified as wander and at or above 10 Hz as jitter.

Clock jitter significantly impacts the eye diagram of transmission signals, which is crucial for assessing the quality of high-speed digital communication systems. The eye diagram visually represents the signal quality by overlaying multiple waveforms, with the eye opening indicating timing and voltage margins. When clock jitter occurs, it causes deviations in the timing of signal edges, leading to a narrowing of the eye opening. This reduction in eye size makes it more challenging for the receiver to accurately sample the data, particularly at higher data rates where the same amount of jitter represents a more significant percentage of the bit period. Higher value of jitter introduces higher bit error rates in the transmission system as the correct detection probability decreases with narrow eye opening diagrams. The effects of jitter can vary based on its magnitude, type, and the measurement bandwidth used. Deterministic jitter can create asymmetric eye openings, while random jitter uniformly reduces the eye size.

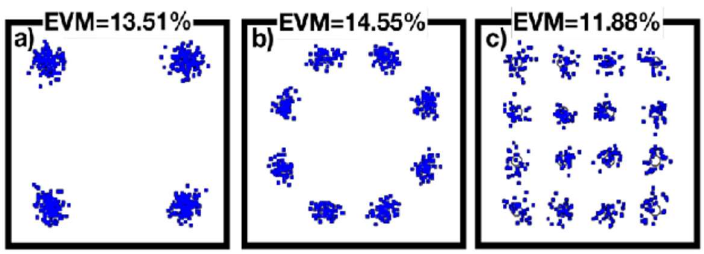
12 kHz to 20 MHz jitter bandwidth was defined by telecommunications standards organisations (like ITU-T) for systems such as SONET (Synchronous Optical Network) and SDH (Synchronous Digital Hierarchy). These standards helped maintain signal integrity and synchronisation, ensuring interoperability across different equipment and networks. The choice of this range became widely adopted as part of these legacy standards and has continued to be applied to other modern transmission systems. The bandwidth range has evolved into a standard range used in transmission systems because it effectively captures the jitter components that significantly impact system performance, even though the higher transmission speed systems based on Ethernet use higher bandwidth to specify jitter.

Fig. 1: A sample eye diagram of a transmission system [7]



Phase noise is mainly associated with quadrature modulation systems, where any phase movement can smear the signal constellation. This smearing adversely affects the error vector magnitude (EVM), which is a critical measure of signal quality; therefore, minimising the EVM contribution from the clock is essential for maintaining signal integrity. In these systems, phase noise from frequency offsets close to the carrier frequency and very high frequencies becomes increasingly crucial. When frame sizes range from a few milliseconds to tens of milliseconds, the close-in carrier frequencies exhibit lower variations, which helps keep the constellations clean and distinct.

Fig. 2: Constellation diagrams and EVM measurements [8]



Conversely, higher frequency offsets are crucial for maintaining the clarity of the constellations, as they help to mitigate the effects of phase noise. As communication systems evolve towards higher-order modulation schemes, such as 256 QAM or even 1024 QAM, it becomes imperative to minimise the reference oscillator's phase noise contribution. High-order modulation requires a cleaner signal to prevent increased bit error rates, making the quality of the reference oscillator a vital factor in achieving reliable and efficient data transmission. In summary, managing phase noise and ensuring minimal contributions from the clock oscillator are essential for optimising performance in advanced modulation systems, enhancing overall communication reliability.

Amplitude Variation on the reference clock solutions

Multiple sources contribute to the amplitude variation effect on oscillators. The amplitude-frequency impact corresponds to the dependence of a resonator's frequency on the oscillation level and appears as a distortion of the amplitude and phase resonance curves. The oscillator design takes care to minimise the effect as much as possible. However, in all practical oscillators, an amplitude variation could happen because of the inherent nature of the oscillation technique. Quartz oscillators have minimal impact on the amplitude-frequency effect compared to other oscillator technologies [4].

Power supply noise contributes to oscillator amplitude noise by introducing fluctuations in the voltage supplied to the oscillator. These voltage variations impact the output amplitudes, even in small proportions, especially in sensitive.

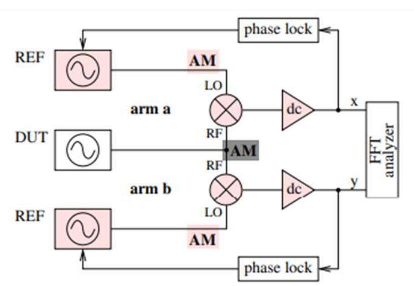
The random walk behaviour of oscillators refers to a phenomenon where the phase or frequency of an oscillator gradually drifts over time due to random noise processes. This random walk is often driven by various noise sources, such as thermal noise, flicker noise, or other environmental variations, which accumulate over time. While this primarily affects the phase or frequency stability, noise processes that cause the phase or frequency to walk randomly can also affect the signal's amplitude. It is essential to highlight that the contribution of this towards the stability of the signal is almost negligible except for oscillators in long-term holdover behaviour.

Amplitude variations do not affect systems, as the end systems are more concerned about the phase variations, resulting in jitter and phase noise. As we see in the later sessions of this technical note, the measurement systems will also include the impact of amplitude variations of the signal in the measured result, which causes inaccurate information about the clocks' performance.

Impact of amplitude variations on the output phase noise spectrum

In a phase noise measurement systems, the DUT signal is mixed with a local reference and the mixer acts as a phase detector which produces a voltage signal level dependent on the phase error which is then measured through an ADC and an FFT analysis performed. A typical block diagram of the system is illustrated below [10]:

Fig. 3: A sample eye diagram of a transmission system [10]



The measurement system can misinterpret AM noise as phase noise due to DC offset caused by mixer asymmetry. This conversion occurs in the mixer, which is designed to detect phase variations. However, the mixer output includes both phase noise and amplitude noise.

The output voltage V_{out} can be expressed as:

$$V_{out} = G_{\varphi}\varphi(t) + G_{\alpha}\alpha(t)$$

where G_{φ} is the phase-to-voltage gain, and G_{α} is the amplitude-to-voltage gain.

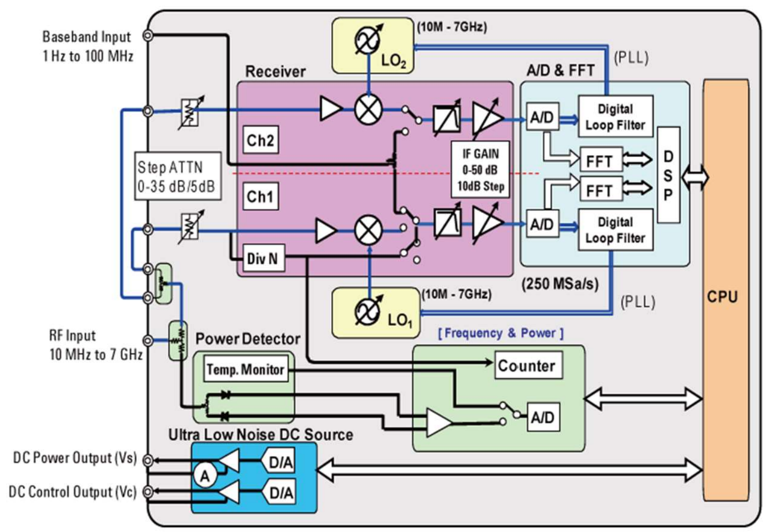
A DC offset arises because of the amplitude noise component \(\alpha(t) \) due to mixer asymmetry. This offset affects the output voltage, which is intended to reflect only phase noise. Consequently, the measurement system mistakenly interprets this DC offset as phase noise. The result is that AM noise is erroneously incorporated into the phase noise measurement.

This misinterpretation occurs because the system uses a cross-correlation technique that does not distinguish the AM-induced noise, treating it as correlated noise common to both arms of the system. Therefore, any AM noise present in the signal is incorrectly classified as phase noise, potentially leading to inaccurate phase noise measurements.

Phase noise measurement model with spectrum analysers

An overview of the functionality of the Spectrum analyser is depicted in the block diagram below [9]:

Fig. 4: Functionality of the Spectrum analyser [9]



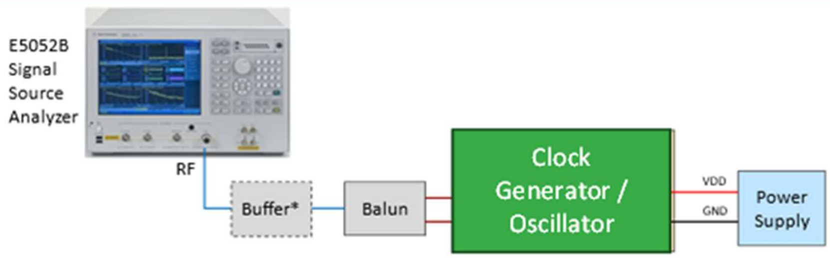
The common spectrum analyser used in standard measurements have the similar blocks and are interpreting the amplitude variations as phase noise error.

An Improved method for phase noise and jitter measurements

While amplitude variations in clock signals do not directly impact the performance of communication systems, they can significantly influence the results of phase noise measurements. This is because spectrum analysers, commonly used for phase noise measurements, treat both amplitude and phase fluctuations equally. As a result, the measured phase noise spectrum may include contributions from amplitude variations, leading to an inaccurate representation of the accurate phase noise characteristics. To address this issue, a method has been proposed to isolate the effects of phase noise from amplitude variations during the measurement process.

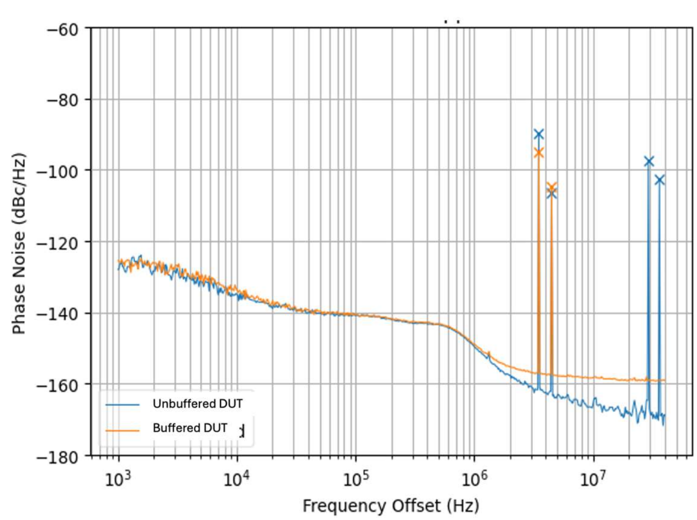
Before performing the phase noise measurement, the clock signal should be passed through high-quality buffers or limiters to limit its amplitude variations. A high-gain, well-designed clock buffer will limit the amplitude variations and only pass along phase variations. This ensures that the signal presented to the phase noise measurement equipment has a stable amplitude, minimising the contribution of amplitude fluctuations to the measurement.

Fig. 5: The measurement method avoids the impact of amplitude variations



In the below measurement example, the blue coloured curve represents a measurement with the the phase noise measurement straight from the DUT. It shows 4 spurs on the curve, various artefacts of the oscillator. The second curve on red is after the DUT is buffered, which limits the amplitude variation of the signal and thus the phase noise has the two spurs eliminated. The red curve represents the results that impact most of the application requirement on the systems using the reference clock.

Fig. 6: Phase noise measurement with and without external buffer to limit amplitude variations



High-end clock sources have significantly lower phase noise compared to many silicon buffers available today. As a result, their measurements need to be combined manually to obtain an accurate jitter measurement. The conversion from phase noise to RMS jitter is done by integrating the phase noise over the desired bandwidth. The final jitter value is determined by adding the raw phase noise without spurs to the spurs when they are turned on.

The final jitter result is obtained as:

$$jitter_{modified} = \sqrt{\left(jitter_{spurs\_off\_no\_buffer}\right)^2 + \left[\left(jitter_{spur\_buffer}\right)^2 - \left(jitter_{spurs\_off\_buffer}\right)^2\right]}$$

The amplitude impacted jitter is essentially the jitter measurement made without the buffer (blue line) with the spurs omitted added to the jitter due to the spurs captured in the measurement obtained with the amplitude limiting buffer buffer (orange line).

Summary

The technical note presents a new technique for improving the accuracy of jitter and phase noise measurements in communication systems by addressing the impact of clock amplitude variations. Jitter and phase noise are critical for evaluating signal quality, and accurate measurements can lead to better system design or data corruption. One of the primary challenges in measuring these parameters arises from amplitude fluctuations in the clock signal, which can distort the accurate jitter and phase noise characteristics when using spectrum analysers. Typically, spectrum analysers treat both amplitude and phase fluctuations equally, leading to an inaccurate representation of phase noise if amplitude variations are not controlled.

To mitigate this issue, the note proposes using a buffer or limiter before performing phase noise measurements. By passing the clock signal through these buffers, the amplitude variations are minimised, allowing the spectrum analyser to focus on measuring phase noise with greater precision. This technique isolates phase noise from amplitude noise, more accurately representing the signal's actual performance. This buffer is especially critical in systems where precise timing and low jitter are essential for high-speed data transmission, as it ensures that amplitude-induced distortions do not corrupt the measurement results.

Definitions

Jitter refers to the variations in the timing of signal edges from their ideal positions in time. It manifests as random fluctuations in the clock signal, affecting the predictability and stability of digital communications. Jitter can be categorised into two main types: deterministic jitter (Dj), which is predictable and caused by specific factors, and random jitter (Rj), which is inherently unpredictable.

Phase Noise, on the other hand, describes the short-term variations in the frequency of a signal, typically observed in the frequency domain. It represents the noise spectrum around an oscillator signal and can be measured using spectrum analysers. Phase noise is particularly relevant in analogue signals and affects the performance of phase-modulated signals by altering the constellations used in digital communication.

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