On Standards for Jitter Measurement
-A Comparative Study

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Abstract

There are a number of standards that define key terms related to measurement. Each and every standard has certain terms defined, and IEEE has been considering writing up a new standard in the measurements of jitter. In order to write up this new standard, there is a need for identifying the key terms that need to be defined in a more significant manner. Hence, the committee of standard has been showing willingness to review the current standards. The reviewing will be done identify all of the terms that have been defined in the standards, and assessing what all terms have been defined in least number of standards.

This report has provided detailed information of several standards that have defined various terms such as jitter, wander and certain related key words. Brief description of these key words has been done in this paper. It is important to understand certain terms that have been defined in a number of standards and what all terms have to be defined yet. Further ahead, the standards that have been referred to in this paper include 39 standards that have been listed in Appendix A, we find out the information about the keywords in these standards and make a comparison with them.

Keywords: Jitter, wander, Phase noise, time error, frequency error, frequency noise
<table>
<thead>
<tr>
<th>Acronym</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>LADC</td>
<td>Analog to Digital Converter</td>
</tr>
<tr>
<td>BER</td>
<td>Bit Error Ratio</td>
</tr>
<tr>
<td>BERT</td>
<td>Bit Error Ratio Tester</td>
</tr>
<tr>
<td>BUJ</td>
<td>Bounded Uncorrelated Jitter</td>
</tr>
<tr>
<td>DDJ</td>
<td>Data depended Deterministic Jitter</td>
</tr>
<tr>
<td>DJ</td>
<td>Deterministic Jitter</td>
</tr>
<tr>
<td>FFT</td>
<td>Fast Four transform</td>
</tr>
<tr>
<td>IEEE</td>
<td>Institute of Electrical and Electronics Engineers</td>
</tr>
<tr>
<td>ISO</td>
<td>International Organization for Standardization</td>
</tr>
<tr>
<td>ITU-T</td>
<td>International Telecommunication Union for standardization for Telecommunication sector</td>
</tr>
<tr>
<td>PDF</td>
<td>Probability Density Function</td>
</tr>
<tr>
<td>PJ</td>
<td>Periodic Jitter</td>
</tr>
<tr>
<td>PLL</td>
<td>Phase-Locked Loop</td>
</tr>
<tr>
<td>PM</td>
<td>Phase Modulation</td>
</tr>
<tr>
<td>PRBS</td>
<td>Pseudorandom Bit Sequence</td>
</tr>
<tr>
<td>NRZ</td>
<td>Non-Return-to-Zero</td>
</tr>
<tr>
<td>CDR</td>
<td>Clock and Data Recovery</td>
</tr>
<tr>
<td>RMS</td>
<td>Root Mean Square</td>
</tr>
<tr>
<td>ISI</td>
<td>Inter-Symbol Interference</td>
</tr>
<tr>
<td>DCD</td>
<td>Duty Cycle Distortion</td>
</tr>
<tr>
<td>BUJ</td>
<td>Bounded Uncorrelated Jitter</td>
</tr>
<tr>
<td>TIA</td>
<td>Telecommunication Industry Association</td>
</tr>
<tr>
<td>RJ</td>
<td>Random Jitter</td>
</tr>
<tr>
<td>TJ</td>
<td>Total Jitter</td>
</tr>
<tr>
<td>ACD</td>
<td>Automatic Call Distributor</td>
</tr>
<tr>
<td>TCXO</td>
<td>Temperature Compensated Crystal Oscillator</td>
</tr>
<tr>
<td>PCM</td>
<td>Pulse Code Modulation</td>
</tr>
<tr>
<td>IEC</td>
<td>International Electronic Commission</td>
</tr>
<tr>
<td>PAS</td>
<td>Publicly Available Specification</td>
</tr>
<tr>
<td>SAW</td>
<td>Surface Acoustic Wave</td>
</tr>
<tr>
<td>PDH</td>
<td>Plesio-chronous digital hierarchy</td>
</tr>
<tr>
<td>SDH</td>
<td>Synchronous Digital Hierarchy</td>
</tr>
<tr>
<td>ANSI</td>
<td>American National Standards Institute</td>
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Chapter 1: Introduction

Volume and speeds of transmitting data have been continuously and increasingly supporting unrestricted growth in the flow of traffic over the backbone of internet mainly because of the movies being spread and other services for the delivery of content being available [1]. The need for having infrastructure of communication with high speed has resulted in increasing the strong demand for the sources of reference signal with high frequency that help in providing stability in the output signals [2]. Communicating without any errors is one aspect that is desired by every user. Transmitting digitally has the ability of avoiding completely total degradation induced by noise. A reason for digital reality to not meet the desired quality is the mistiming present in the equipment of transmission when regeneration of data takes place. Whenever there is large mistiming, errors are generated and this makes the system not fit for use. Even with lower mistiming values, amplitude sensitivity and variations of phase enhances making performance to suffer. This mistiming indicates a variation and this variation has either a slow degree or a high varying speed. When variations are slow in the timing of the signal as seen from the perspective of a system then it is termed as a wander and with higher varying speed it is termed as jitter. 10 Hz is the division present between jitter and wander. From this perspective it can be said, jitter acts as important cause for the errors received in data [3]. These errors are mainly due to the changes in the timings when the signal transition horizontally changes its position to match that of the sampling point [4]. However, transmission systems have a jitter performance which has been made mandatory though standards that are written through governing bodies such as IEEE and ITU-T. Then the jitter performance is referenced through specifications of the equipment. Jitter performance from this perspective has 3 measurements and specifications and the standards also refer to these which are output jitter, tolerance of jitter and transfer jitter. In order to deal with jitter measurement in an appropriate manner, it is required for jitter standards to be improved and various new standards have been developed and proposed e.g. ITU-T IEC and IEEE. For acknowledging the new standard that IEEE is focusing upon, it becomes essential
to understand the process of jitter measurement, its related keywords and the existing standards. This standard is termed as P2414 standard developed for facilitating accuracy and precisely communicating with regard to presence of jitter, phase noise and the methods to measure them.

**Resource Background**

In order to reduce the disturbance caused, jitter is in a standard manner measured through various standards. This research thesis focuses on the research standards to conduct an overview of the various standards employed for measuring jitter and certain recommendations have been provided after understanding these standards. For the purpose of this study, the measurement methods used to measure jitter, are classified as either research methods or standard methods. Comparison is made between the methods that have been proposed in recent research publications on jitter measurement and the methods that are enforced as standard methods.

This report has been prepared in order to explore the jitter measurement process, various key words involved and the standards of measuring jitter. This report is inclusive of more than 20 different present standards to find out the range till which they have covered the topic of jitter. With the help of these topics based exploration much can be gained to depict the status of jitter measurement and its standards. Furthermore, the keywords discussed in this paper are inclusive of jitter, wander, phase noise, time error, frequency error, frequency noise which have been selected because they are important for understanding jitter measurement standards. In order to do this research, we reviewed the standards which have been listed in the reference.

**Methods for solving the issue**

Since recent times, it has been found that IEEE has been working on a new standard, P2414 Standard for Phase Noise and Jitter. The key purpose of this standard is focused on facilitation of precise and accurate communication that has concerns with phase noise and jitter, along with the methods used for
its measurement [5]. Due to the broad scope of applying these types of terms in the industries of electronics like industries of telecommunication, computer, and instruments for measurement, presenting methods for measuring these, and development of unambiguous definitions are relevant for communication amongst consumers, users and manufacturers [6].

There is an extremely broad application of the terms phase noise and jitter within the industries of electronics. There has been generation of a lot of literature for dealing with these. There are a number of misconceptions regarding what can exactly be referred to as jitter as there are huge variations in the definition being highly dependent on the particular application [7]. As a matter of fact, there is no denial in the fact that there is not a single, particular, universally approved and comprehensive specification that defines phase noise, wander and jitter.

What’s more, we have filled out the forms [Appendix B] for all the standards that have been listed in appendix A, and hand in these to our supervisor.

**Resource used**

For the purpose of this report, a literature study carried out on jitter, and how it affects the communication system, has been considered. Our study comprises of the research work previously done on jitter for obtaining notes that may be applicable for the literature study. Some of the key words that were focused on during the study include jitter measurement, jitter and random jitter measurement. The selection criterion was specifically based on the use of Institute of Electrical and Electronics Engineers (IEEE Xplore), International Electronic Commission (IEC), International Organization for Standardization (ISO), International Telecommunication Union for standardization for Telecommunication sector (ITU-T), American National Standards Institute(ANSI) and Telecommunication Industry association (TIA).
Research Outline

This research is inclusive of 4 chapters with each chapter holding its individual significance. The first chapter that is introduction has provided an overview of this research, the main problem being addressed along with the methods that will be used for addressing the issue. The second chapter is a literature study performed through consideration of various literature articles to enlighten the methods available. Furthermore, Chapter 3 is inclusive of data processing through literature review and then analysis. The final chapter is the conclusion chapter providing adequate explanation to the overall requirement of this research.
Chapter 2: Theory

This chapter provides theoretical explanation regarding the problem statement. There are a number of misconceptions regarding what can exactly be referred to as jitter as there are variations in the definition being highly dependent on the particular application [7]. So we reviewed the articles to find out the information about all keywords.

Jitter Classification

Jitters can be classified into two groups that are random jitters and deterministic jitters that has been shown in Figure 1. Deterministic jitters (DJ) can be further subdivided into three categories that are data dependent jitters (DDJ), bounded uncorrelated jitter (DUJ) and periodic jitter (PJ). Data Dependent Jitter can also be further distinguished into two types that are Duty Cycle Distortion (DCD) and Inter-Symbol Interference (ISI). Figure 1 depicts this classification of jitters.

Figure 1: Total Jitter Classification [8]
Jitter

The term jitter is referred to as the deviating point from the actual periodicity of a periodic signal being presumed in telecommunications and electronics. The observation of jitter can be done in a number of features like the amplitude of signal, frequency held by successive pulses, or phase in the periodicity of signal [3]. Jitter, in general terms, is an undesired and mostly significant factor within the design of each and every link of communication. In the applications for the recovery of clock, it is referred to as the timing jitter [8]. The quantification of jitter can be done with respect to similar terms as all signal varying with time.

Analyzing Jitter in Domain of Time

There are many ways to study jitter in the domain of time. But eye diagram is an easy understanding way. For the purpose of the report, here is the introduction of eye diagram.

![Figure 2: Diagram of Eye with specific terms defined][10]

In terms of telecommunication, a diagram of eye is the display of oscilloscope within which a signal of digital data from a receiver is the repetitive sampling and applying the vertical form of input, while the rate of data is used for triggering the sweep in horizontal form.

From the Figure 2, it is evidenced that the “eye opening” ranges from 1 unit interval to the left and 1/2 unit interval to the right of the eye centre that displays the transitions for rise/fall timings. The total time axis ranges for only 2 bits. The eye opening is representative of the amount of effect jitter has on

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[10]: diagram_of_eye.png
data signals and to what extent it affects it. Any signals with an ISI results in a small eye opening in an eye diagram, it is important to understand that an eye opening is depending on the extent to which the ISI affects the data signal. By the use of time sampling oscilloscopes, eye diagrams can be made; Figure 2 is representative of a typical eye diagram. Additionally, the following equation can be used to determine the extent to which a clock signal is affect by jitter. In the equation,

$$V(t)= (A+E(t))\sin(2\pi f_0 t + \varphi(t))$$

“$$\varphi$$” is the phase of the noise term i.e. phase modulation (PM) that is capable of causing jitter and “$$E(t)$$” refers to the amplitude of the noise term i.e. amplitude modulation (AM). Similarly, it is possible to perform a DJ or RJ test in the time domain analysis. This technique is relatively new when analyzing any type of time jitter since this technique allows the separation the total jitter of a signal into either deterministic components or random components.

**Random Jitter**

Total jitter (TJ) refers to the combined total of random jitters and deterministic jitters. When relating total jitters to bit error ratio, TJ (BER) i.e. total jitter at bit error ratio is obtained. The TJ (BER) value refers to the eye closure in an eye diagram i.e. to what extent the “eye” closes in a standard eye-diagram. This value can be obtained by subtracting the eye opening from the width of the eye. It is important to note that the larger the TJ (BER) value, the longer is the eye closure in the eye diagram.
Deterministic Jitter

Deterministic jitter can be distinguished from random jitters by the difference in its property and its definition. Deterministic jitters can be defined as DJ (p-p) which means peak-to-peak value. As previously mentioned, deterministic jitters can be further subdivided into small sub-components which include ISI, DCD and PJ where periodic jitters are another example of nondependent data jitter. However, data dependent distribution jitters which consist of ISI and DCD jitters are data dependent jitter. Deterministic Jitter not depended on data: As mentioned above, period jitters and bounded uncorrelated jitters are non-data depended deterministic jitters.

1. Period Jitters: a jitter will be considered as a periodic jitter only when there is a displacement in the timings of the falling and rising of the edges, that follows a periodic pattern. These may consists of sinusoidal signals that modulate the phase of the ideal data signal or clock signal. Hence, this can also be referred to as sinusoidal jitter. Some sources of periodic jitters include, signal coupling, EMI and cross-talk. Most of the times, no time relationship is noticed between the serial data signal and the source of periodic jitter. A jitter spectrum display allows identification of the presence of periodic jitters.

2. Bounded Uncorrelated Jitter: These jitters are known to have a bounded distribution that is Gaussian where such distribution has a limited bandwidth i.e. without any tail. It allows one to specify the peak-to-peak values. Also, these can be referred to as bounded random jitters and can be created via filtering the Pseudo Random Bit Sequence (PRBS) data stream.

From this perspective, jitter is the variation of timing of a signal edge set from their values ideally. In clock signals, jitter typically is caused through any disturbance or more prominently through noise within systems. Thermal noise, variations in power supply, conditions of loading, noise of the device and the couple interference from circuits nearby are all contributing factors. Apart from the broad classification of jitter, measuring jitter is possible in various ways and there are various types of hitters
further inclusive of period jitter, period jitter cycle to cycle, and jitter is from phase and error interval in time.

Period Jitter is the cycle time deviation of a signal clock with regard to ideal period throughout a number of random cycles selected. If a number of periodic clocks individually are given then it becomes possible to measure each individually and it is also possible to calculate the period average clock along with the value of peak to peak and standard deviation. This deviation and the value of peak to peak are referred frequently to RMS values and peak to peak periodic jitter.

This type of jitter is often used in calculation of digital systems timing margins. For example if a system based on microprocessor is considered wherein the processor needs data setup of 1 ns prior to the rise of clock then the clock’s rising edge can happen before the validation of data. Therefore presentation of microprocessor will be done with data which is incorrect. Such an example is depicted through the Figure 3:

![Figure 3: Validation of data setup caused through jitter clock [11]](image)

In the same way, if another data base microprocessor has a holding time required of about 2 ns then the clock jitter will have positive value and the holding time of data will be reduced in an effective manner. Here again incorrect data will be seen by microprocessor as depicted Figure 4:
Figure 4: Violation of data hold time caused through clock jitter [12]

Peak to Peak Jitter from RMS Jitter

As the periodic jitter from a clock has random values when measured on distributive index of Gauss and so it becomes possible to express it completely with regard to value of root mean square in ps. The peak to peak value however is more essential to calculate the setups and for holding the budgeting time. For converting the jitter of RMS to the jitter of peak to peak for a 10000 sample size, the equation can be used by a reader:

\[
\text{Peak-to-peak period jitter} = 7.44 \times (\text{RMS jitter})
\]  

[13]

An example can be quoted here if the jitter in RMS form is 3 ps then the jitter of peak to peak will be 11.16 ps [2]. The derivation of the Equation is done from the table of Gaussian probability density function as illustrated in the Table 1:

<table>
<thead>
<tr>
<th>Sample Size</th>
<th>Sigma (σ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>±1.282</td>
</tr>
<tr>
<td>100</td>
<td>±2.327</td>
</tr>
<tr>
<td>1,000</td>
<td>±3.090</td>
</tr>
<tr>
<td>10,000</td>
<td>±3.719</td>
</tr>
<tr>
<td>100,000</td>
<td>±4.265</td>
</tr>
<tr>
<td>1,000,000</td>
<td>±4.754</td>
</tr>
<tr>
<td>10,000,000</td>
<td>±5.200</td>
</tr>
<tr>
<td>1,000,000,000</td>
<td>±5.612</td>
</tr>
<tr>
<td>10,000,000,000</td>
<td>±6.998</td>
</tr>
<tr>
<td>100,000,000,000</td>
<td>±6.362</td>
</tr>
<tr>
<td>1,000,000,000,000</td>
<td>±7.035</td>
</tr>
</tbody>
</table>

Table 1: Gaussian probability density function [8]
Wander

Wander is referred to as the magnitude in the variation of phase, in consideration with the clock of reference or the signal of data. Wander is also depicted as a slow frequency phase variation of DC. It needs wide range of measurement in comparison to jitter. The items of wander measurement are Time Interval Error (TIE), Maximum Time Interval Error (MTIE), and Time Deviation (TDEV). Time Interval error is defined as a differential phase between measured signals and the referential signal. The unit is general acknowledged using ns. The measurement time phase difference is measured from the initial time defined as 0. Therefore TIE depicts the change phase from the start of measurement. MTIE is responsible for measuring the frequency offset characteristics and a Wander phase transient. MTIE is evaluated through use of parameters such as Observation Time. In all the data of TIE, the time range is shifted as it holds the peak value so that MTIE can be calculated on the basis of TIE measurement. Such calculated MTIEs are the values of MTIE at a time range and it consistently calculates at each time range. TDEV on the contrary is the measurement of spectrum quantity characteristics within Wander. It can be evaluated through use of parameters such as time observation. In the value of TIE, TDEV can be defined as RMS in conjunction with Band Pass filter wherein the central frequency is at 0.42 per time range.

Wander is of various types such as output wander, wander generation, input noise wander tolerance and noise wander transfer. The output wander is responsible for evaluating noise wander generated when network element (NE) is connected within a network. Its evaluation is done through MTIE and TDEV measurement confirming that nothing is more than the mask line specified. The generation of noise wander measures the noise wander developed from the device under test through itself. It is corresponding in nature to jitter and shows the wander emergence amount when wander free signal is input. The wander of input noise tolerance is responsible for measuring the device tolerance under tests in opposition to noise wanders.
Phase Noise

Phase noise is referred to as small uncertainties or fluctuations on random basis within the phase in which there is an involvement of electronic signal [4]. Stating in general sense, the engineers of radio frequency speak regarding the phase noise related to an oscillator, and on the other hand, the engineers of digital system seem to be working with the jitter as a part of the clock.

Furthermore, Phase noise frequencies are mostly always high than the floor noise that appears near the frequency of the carrier. Noise can be expressed as an equation as follows:

Ideal signal:
\[ V(t) = A \sin 2f_0 t \]

Actual signal:
\[ V(t) = (A + E(t)) \sin(2\pi f_0 t + \phi(t)) \]

Here \( E(t) \) is the AM noise, \( \phi(t) \) is the PM noise or phase fluctuation.

In brief phase noise is stated usually as a ratio between the power of the carrier and the noise at the carrier’s offset frequency.

Phase Jitter

As already evident phase noise is described usually as a noise values set at several offsets of frequency or as a consistent plot of noise over a frequencies range. The phase noises integration over a specific spectrum and the seconds expressed are termed as phase jitter. In a wave of square, most energy is situated at the frequency of carrier. Some signal energies however are leak out throughout a frequencies range on both carrier sides. From this perspective, phase jitter is the phase noise energy amount consistent between two frequencies of offset which are relative to the carriers [14].

We get the equation of the RMS phase jitter between two different frequencies:
Where in, \[ \int_{f_1}^{f_2} \frac{PN(f)}{10} \, df \] is the power noise present between \( f_1 \) and \( f_2 \) on every side of frequency carrier. Which \( f_1 \) is lower frequency, \( f_2 \) is higher frequency, \( c \) is capacitance, and \( PN(f) \) is the frequency of phase noise. Common applications of the same and the associated filters bandwidth are inclusive of fibre channel (637 KHz to 10 MHz), 10 gigabit Ethernet (1.875 MHz to 20MHz) and SATA or SAS (900 KHz to 7.5 MHz).

If the function of filter is \( H \) then the RMS phase jitter filter can be calculated by using the equation:

\[
\text{RMS Phase Jitter (filtered)} = \sqrt{\int_{f_1}^{f_2} \left( \frac{PN(f)}{10} \left| H(f) \right|^2 \right) df \over 2\pi c} \tag{8}
\]

**Time Error**

In the historical sense, time error, also referred to as the maximum time- interval error is one of the key quantities of domain and time. These quantities are considered for specifying the requirements in stability of clock within the scope of the standards available. As stated by the new international standards of telecommunications, five quantities for stability have been identified for the specification of clock [7]. These are the time deviation, Allan deviation in its modified form, Allan deviation, maximum time interval error, and the square root of the mean for time interval error.

Time Interval Error (TIE) of a time deviation edge from the ideal position is measured by taking account the reference point. TIE, in effect is the representative discrete domain of time expressed by phase noise. The Figure 5 provides explanation on TIE based basic concept. The signal ideally is created in software’s from average signal period estimate.
Time Deviation is also called as $\sigma_x(\tau)$, which is the phase time stability in opposition to intervals of observation of measured source in the clock. The deviation of time therefore forms a deviation type standardized way of measurement for indicating the signal source time instability. This is the Allan deviation illustrating frequency stability scaled variant. It is defined commonly from the modified deviation of Allan but other estimates can as well be used.

![Figure 5: TIE measurement of an edge [7]](image)

**Frequency Error**

In terms of telecommunications, frequency error is referred to as the difference or variation between the actual frequency and the frequency that has been scheduled.

The frequency error measurement is performed by a narrow measurement band consisting of quality modulation and accuracy in frequency. This set acts as a test to measure the error in frequency, rms error of phase and error of peak phase. The measurement of frequency error leads towards demodulating data and comparing the wave form measurement with ideal forms of waves expected for the received data. The error in frequency is therefore the difference lying in frequency after
modulation effect is adjusted for and phase error is checked between the transmissions of RF. This error in frequency however happens only under the following conditions:

Two different instruments use different references of frequency: Frequency counters base models are equipped usually with Temperature Compensated Crystal Oscillator (TCXO) based references of frequency which are inexpensive along with frequency stability at 1 to 5 ppm. An issue developed by the reference of frequency leads towards adding a measurement results error. Figure 8 depicts the way in which frequency counter based measurement results can be different when internal reference of TCXO is used in comparison to external rubidium reference of high-precision.

![Figure 6: Results of frequency measurement of a 25 MHz oscillator [13]](image)

Difference in specifications of gate time or instrument also adds to frequency error. Results from different measurement can be apparently due to use of similar reference of frequency when using distinct times of gate. If the gate times and the references have similarity but the resolutions of the instrument are same then the results will be different at the low times of gate.

**Frequency Noise**

Frequency noise is referred to as fluctuations taking place in instantaneous frequency on random basis related to the signal of oscillation. This noise developed from the circuits of crystal oscillators. When the circuits are used the noise is developed through components of the circuits, components of noise and characteristics of the loop. The frequency noise further is indicative of signal phase fluctuation.
Henceforth, when time domain is observed it is apparent as a jitter in wave form. Frequency noise and jitter are both indicative of signal stability and share a collaborative relationship.
Chapter 3: Method


Jitter Standards

The full names of all standards are listed in Appendix A.

IEEE 1521: A metrics set and process for enabling consistency when measuring time interval error in the signals synchronized videos provided by this standard.

IEEE 1007: The main purpose behind this standard is focused on providing requirements for the test equipment and the methods to test the characteristics of transmission in the systems, circuits, and equipment of PCM (Pulse-Code Modulation) telecommunications.

IEEE 1139: This set standard presents the standard generators of frequency, where there is an inclusion of quartz oscillators, cavity oscillators, oscillators based on thin-film resonator, sapphire oscillators, YIG (yttrium-iron-garnet), dielectric resonator oscillators, and atomic standards of frequency.

IEEE C37.94: IEEE is a standard of IEEE that contributes in defining the rules for the interconnection of multiplexer and tele-protection devices for the companies of power utility.
IEC 60235: It is an international standard that introduce the measurement of the electrical properties of microwave tubes.

IEC 60679-6: As per the specific scope of this standard, the application of the publicly available specification (PAS) is done to the measurement of phase jitter related to SAW oscillators and a quartz crystal oscillator utilized for the electronic equipment and devices, and provides guidelines and recommendations to the phase jitter that assists in accurately measuring the jitter of RMS.

JESD65B: This particular standard contributes in defining the specifications of skew and testing of skew for the standard devices of logic.

ISO/IEC 9314-9: With the drafting of this particular standard, the Interface of Fibre Distributed Data has the intension for being used with high performance with the basic purpose of network with multiple stations and the designing of this has been done as an operation with high efficiency having data rate of 100M bit/s at the peak point.

ISO/IEC 9314-20: This particular standards deals with the suite of test for the physical medium dependent conformance testing for the interface of fibre distributed data.

ISO/IEC 14165-117: As stated by the scope of this standard, the specifications and methods of measurement have the intension of being utilized as a significant part in the total performance of signal complying with the set of requirements where the content of phase related to the signal is considered and involved.

ITU-T 0.171: This standard acts as a compliant device with synchronous digital hierarchy. It is traditional test equipment used for testing systems of Plesio-chronous digital hierarchy (PDH). The standard was previously also used as being the base to design the equipment’s of Synchronous Digital Hierarchy (SDH) tests.

ITU-T 0.172: The main purpose of this standard lies clearly in defining the equipment tests needed to verify that the equipment of SDH networking are working properly when jitter levels are allowed and is not generating increased jitter levels.
ITU-T 0.173: This particular standard is focused on the equipment for the measurement of jitter by the digital systems on the basis of the network of optical transport.

ITU-T 0.174: As per the scope of this particular standard, the specification of test equipment has been done within the recommendation that consists of principles related to the functions of measuring wander and jitter and the function for the generation of wander and jitter.

ITU-T G.803: As per the scope of this particular standard, there is an outlining of requirement for the devices of timing utilized in the synchronization of network equipment, the operation of which is conducted in accordance with the governance of principles by the synchronous hierarchy of digital world.

ITU-T G.813: As per the recommendations of this particular standard, specification has been made towards important parameters and their restricting values that have the ability of controlling the value of wander and jitter in a satisfactory manner at the interfaces of network node related to the hierarchy of plesiochronous digital world and synchronising the network that have a base of the initial level bit rate of hierarchy of 2048 kilo bites per second.

ITU-T G.823: This particular standard is known for defining the control of wonders and jitters in the networks of digital technology on the basis of a hierarchy at 1544 kilo bytes per second. This particular standard contributes in illustrating the maximum limit of jitter as under the recommendation provided by the standard of ITU-T G.823.

ITU-T G.824: Within the scope of this particular standard, amendments have been made that consist of modified texts and contents for being added to the part of recommendation.

ITU-T G.783: Within the scope of this particular standard, several recommendations have been defined as a library of combinations of rules, and normal building factors that can be combined for the description of equipment responsible for transmission being done in digital form.
**ITU-R BT.1363:** As per the scope of ITU-R BT.1363, this standard contributes in describing the methods for the measurement of jitter performance within the digital interfaces of bit-serial. Jitter has been identified as being one of the most relevant parameters within performing the systems of serial digital transmission.

**ANSI C63.14:** This particular standard helps in providing definitions related to the terms having an association with the compatibility of electromagnetic, the pulse of electromagnetic, and the discharge of electrostatics.

**TIA 334:** The application of this particular standard can be done towards the exchanging of serial signals of binary data and the signals of timing in the entire interface between the synchronous equipment of data circuit termination.
Chapter 4: Results and Discussion

The aim of this chapter is studying the standards of all the keywords that have been mentioned and make a comparison between them. To achieve this purpose, we were looking for these keywords in all standards and marked as shown in Table 2.

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Table 2: The keywords in all standards
It is evident from the Table 2 that jitter is consistent in almost every standard except for TIA 526 and IEEE181.

Wander is also covered by mostly all standards except for some prominent ones such as IEC 60235 and ANSI C63.14. It is also evident that not all the specific key terms are taken care of by all the standards. In the following section these key terms will be compared.

Phase noise, frequency noise, time error and frequency error are only in a few standards. We will compare these futures in the following sections.

**Phase noise**

In IEEE 1139, phase noise is defined as one-half of the phase instability $S_p(f)$. Other standards where phase noise has been addressed are IEEE 1193, ITU-T O. 172, ITU-T G.813, ITU-T G. 823, ITU-T G.824 and ITU-R BT.1363. In each of these the definition of Phase noise is the same as in IEEE 1139.

In standard 1139, within the time domain, the frequency standard unit of measurement as well as the phase instabilities is the completely overlapping Allan deviation. The Allan deviation is defined as the square root of the Allan variance. And for the Allan variance, the equation can be expressed as

$$\sigma_y^2(\tau) = \frac{1}{2} \left\langle \left( \bar{y}_{n+1} - \bar{y}_n \right)^2 \right\rangle$$

Where $\tau$ is the observation period, $\bar{y}_n$ is the nth fractional frequency average over the observation time.

For standard IEEE 1193, in a small index of modulation, the random vibrations contribution to phase noise is understood through the equation:

$$L(f_v) = 20 \log \left( r^* A f_0 / 2 f_v \right)$$

Wherein, $f_v$ is the vibration frequency, $r$ and $A$ are the components of acceleration sensitivity vector and of the acceleration. Here PSD is the vibration based power spectral density. The $L(f_v)$ usage in this standard is in conformance to the standard of IEEE 1139 stating that phase noise degradation can
be caused severely through vibration platforms. In the standard ITU-T O. 172, phase noise is not specifically designed however there are phase variations explained in the form of recommendation. For the standard ITU-T G. 813, phase noise is defined as the Slave clocks (SEC) based generated noise which represents the phase noise amount produced at the level of output when there is an ideal reference signal from the input. In comparison, in standard ITU-T G. 823, phase noise is also present on the incoming signal and it is needed to synchronize the network for providing the nodes at the accommodation. In the standard ITU-T G. 824, phase noise has been most appropriately explained in its definitions illustrating that phase transience exists. Within limited duration phase perturbations at synchronization and interface of traffic, is due to the switching of the clock. The phase transient’s duration caused through clock switch is dependent upon the involved of clock. Furthermore it illustrates that phase transients are specifically elaborated through maximum deviation of phase and through maximum frequency offset temporarily. In the standard ITU-R BT. 1363, there is no specific definition on phase noise however the key term has been addressed in jitter specifications on the same line as the mentioned articles.

**Frequency noise**

Frequency noise is addressed in IEEE 1057, IEEE 1139 and IEEE 1658. In each of these the definition of Frequency noise is the same. The frequency noise specifically is the frequency instability depicted in the domain of frequency and on the contrary jitter is a signal fluctuation in the form of wave within the domain of time.

**Time error**

Time Error is addressed in IEEE 1193, ITU-T G.810 with similar definitions of time error. In accordance to the standard of IEEE 1193, specialists in crystal resonators and oscillators generally characterize phase noise by Sφ(f) or L(f) (refer to IEEE Std 1139-1999 [B59]). Some users of crystal
oscillators, however, characterize phase noise in terms of “phase jitter.” In digital communications, the terms jitter and wander are used in characterizing timing instabilities. Jitter refers to the high-frequency timing variations of a digital signal, and wander refers to the low-frequency variations. For very high Fourier frequencies or short integration times, it may be necessary to calculate the jitter from the spectrum rather than to measure it directly. In comparison according to G.810, the function of time error with regard to standardized frequency is the difference present between clock time and the standard frequency. In mathematical form, the function of time error is denoted as $x(t)$ between time of clock generation $T(t)$ and a reference clock generation time $T_{ref}(t)$ and can be defined as

$$x(t) = T(t) - T_{ref}(t)$$

Therefore, in accordance to this article, time error is a basic function wherein there are different kind of parameter stabilities that can be calculated as the continuous information of $x(f)$ cannot be attained practically.

**Frequency error**

Frequency error is addressed in the standards; IEEE 1193 and IEEE 1521 with similar definitions of frequency error. According to the standard of IEEE 1193, frequency error is defined as the modulated frequency occurring due to disturbance in the network. This definition is also in alignment with the definition of frequency error given under IEEE 1521 standard describing frequency error as the frequency offset rate of change due to some frequency disturbance. Also, the standard is of the notion that it is not possible to have the best of the appliances also with zero frequency error.
Chapter 5: Conclusion

This report was presented for referring to several standards in order to define different terms related to it on an equal level. This report has evidently stated that there is consistency of jitter in almost each and every single standard, but not present in standards of IEEE 181 and TIA 526. There is coverage of wander in almost each and every standard instead of certain prominent standards for example ANSI C63.14 and IEC 60235. There are also certain evidences that not each and every single specific key term are considered by each and every standard. This report has compared some of these key terms with respect to different standards. In addition to this, it has been identified that key terms such as frequency error, time error, frequency noise and phase noise have been explained in some of the standards only. The terms that have been defined in this report include time error, frequency noise, frequency error, and phase noise. There is addressing of the key term, frequency noise in IEEE 1658, IEEE 1139, and IEEE 1057. Further ahead, the key term frequency error has been discussed in certain standards such as IEEE 1521 and IEEE 1193.

For the reference of future, it is important to communicate these findings with the committee of standardization in order to ensure that only the terms that have been defined in least number of standards are to be defined in the new standard. This has to be done in the future context for further accurate development of standards.
References


Appendix A: List of Standard methods

IEEE 181 Standard for Transitions, Pulses, and Related Waveforms
IEEE 686 Standard Radar Definitions
IEEE 743 Standard Equipment Requirements and Measurement Techniques for Analog Transmission Parameters for Telecommunications,
IEEE 1007 Standard Methods and Equipment for Measuring the Transmission Characteristics of Pulse-Code Modulation (PCM) Telecommunications Circuits and Systems,
IEEE 1057 Standard for Digitizing Waveform Recorders,
IEEE 1139 Standard Definitions of Physical Quantities for Fundamental Frequency and Time Metrology--Random Instabilities,
IEEE 1193 Guide for Measurement of Environmental Sensitivities of Standard Frequency Generators,
IEEE 1241 Standard for Terminology and Test Methods for Analog-to-Digital Converters,
IEEE 1394 Standard for a High-Performance Serial Bus
IEEE 1521 Standard for Measurement of Video Jitter and Wander,
IEEE 1588 Standard for a Precision Clock Synchronization Protocol for Networked Measurement and Control Systems,
IEEE 1658 Standard for Terminology and Test Methods of Digital-to-Analog Converter Devices,
IEEE C37.94 Standard for N Times 64 Kilobit Per Second Optical Fibre Interfaces Between Teleprotection and Multiplexer Equipment
IEC 60235 Measurement of the electrical properties of microwave tubes,
IEC 60512-25-6 Connectors for electronic equipment - Tests and measurements - Part 25-6:Test 25f: Eye pattern and jitter,
IEC 60679-6 Quartz crystal controlled oscillators of assessed quality - Part 6: Phase jitter measurement method for quartz crystal oscillators and SAW oscillators - Application guidelines,
IEC 61280-2-3 Fibre optic communication subsystem test procedures - Part 2-3: Digital systems - Jitter and wander measurements,

IEC 61784-2 Industrial communication networks - Profiles - Part 2: Additional fieldbus profiles for real-time networks based on ISO/IEC 8802-3,

IEC 61158-X Digital data communications for measurement and control - Fieldbus for use in industrial control systems,

ISO/IEC 9314-9, Information technology - Fibre distributed data interface (FDDI) - Part 9: Low-cost fibre physical layer medium dependent (LCF-PMD),

ISO/IEC 9314-20 Information technology - Fibre distributed data interface (FDDI) - Part 20: Abstract test suite for FDDI physical medium dependent conformance testing (PMD ATS),

ISO/IEC TR 14165-117, Information technology - Fibre channel - Part 117: Methodologies for jitter and signal quality (MJSQ)

ITU-T O.171 Timing jitter and wander measuring equipment for digital systems which are based on the plesiochronous digital hierarchy (PDH),

ITU-T O.172 Jitter and wander measuring equipment for digital systems which are based on the synchronous digital hierarchy (SDH),

ITU-T O.173 Jitter measuring equipment for digital systems which are based on the optical transport network,

ITU-T O.174 Jitter and wander measuring equipment for digital systems which are based on synchronous Ethernet technology,

ITU-T G.803 Architecture of transport networks based on the synchronous digital hierarchy (SDH),

ITU-T G.810 Definitions and terminology for synchronization networks,

ITU-T G.813 Timing characteristics of SDH equipment slave clocks (SEC),

ITU-T G.823 The control of jitter and wander within digital networks which are based on the 2048 kbit/s hierarchy
ITU-T G.824 The control of jitter and wander within digital networks which are based on the 1544 kbit/s hierarchy, ITU-T G.825 The control of jitter and wander within digital networks which are based on the synchronous digital hierarchy (SDH)

ITU-T G.8251 The control of jitter and wander within the optical transport network (OTN),

ITU-T G.783 Characteristics of synchronous digital hierarchy (SDH) equipment functional blocks,


ANSI C63.14 American National Standard Dictionary of Electromagnetic Compatibility (EMC) including Electromagnetic Environmental Effects (E3),

TIA 334 Signal Quality at Interface between Data Terminal Equipment and Synchronous Data Circuit-Terminating Equipment for Serial Data Transmission,


JESD65B Definition of Skew Specifications for Standard Logic Devices
## Appendix B

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<td>3</td>
<td>Standard number and title</td>
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<td>Year of release</td>
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</table>
| 5 | Scope of the standard  
   (provide a short description of the purpose of the standard along with a short outline of the content of its Chapters – possibly 1000 char. max.) |
| 6 | Does the standard recall terms such as jitter, wander, phase noise, time error, frequency error, frequency noise or any other time-related or frequency-related parameter?  
   (specify Yes/No. If yes, please annotate: i) the definition of all relevant terms as they are reported in the Standard and ii) the exact number of the section/subsection/clause where each definition is located) |
| 7 | How would you classify the relevance of jitter-related topics within the Standard considered?  
   □ High relevance (it is the main topic or one of the central topics of the Standard)  
   □ Medium relevance (it is not one of the main topics of the Standard, but appears in several sections and/or chapters to support/justify/explain other subjects)  
   □ Low relevance (it is just sporadically mentioned in the Standard and/or it appears just/mostly in Annexes) |
| 7b | In case of low or medium relevance, how the jitter is related to the Standard considered?  
   (provide a short description of how and why the jitter or any other related parameter is used in the Standard. Please annotate also the exact Section, subsection or clause you refer to in your explanation) |
| 8 | Does the Standard define any measurement procedure for jitter or other similar parameters?  
   (specify Yes/No. If yes, please annotate: i) a summary of the proposed measurement technique and ii) the exact number of the section/subsection where any of such techniques is explained) |
| 9 | Further comments  
   (please report in this Section any other comment, remark or consideration that you think could complete the analysis of the Standard possibly in no more than 500 char.) |