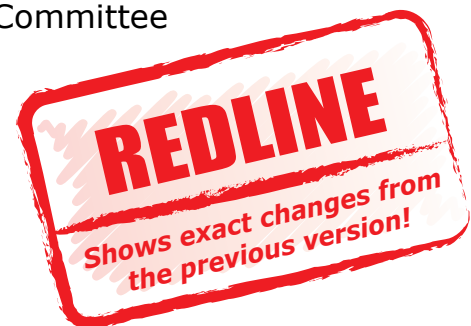


IEEE Standard for Transitions, Pulses, and Related Waveforms

IEEE Instrumentation and Measurement Society

Sponsored by the
Waveform Generation, Measurement, and Analysis Committee



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USA

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IEEE Standard for Transitions, Pulses, and Related Waveforms

Sponsor

Waveform Generation, Measurement, and Analysis Committee
of the
IEEE Instrumentation and Measurement Society

Approved 16 May 2011

IEEE-SA Standards Board

Abstract: Approximately 100 terms and their definitions, for accurately and precisely describing the waveforms of pulse signals and the process of measuring pulse signals, are presented in this standard. Algorithms are provided for computing the values of defined terms that describe measurable parameters of the waveform, such as transition duration, state level, pulse amplitude, and waveform aberrations. These analysis algorithms are applicable to two-state waveforms having one or two transitions connecting these states. Compound waveform analysis is accomplished by decomposing the compound waveform into its constituent two-state single-transition waveforms.

Keywords: aberration, algorithms, compound waveform, histogram, IEEE 181, levels, pulse, pulse amplitude, pulse definitions, pulse measurement, states, state boundaries, state levels, transients, transitions, transition duration, waveforms, waveform analysis, waveform definitions, waveform parameters, waveform terms

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Introduction

This introduction is not part of IEEE Std 181-2011, IEEE Standard for Transitions, Pulses, and Related Waveforms.

This standard was developed by the Subcommittee on Pulse Techniques (SCOPT). It supersedes IEEE Std 181-2003^a. The SCOPT is a subcommittee of the Waveform Generation, Measurement, and Analysis Committee (TC-10) of the IEEE Instrumentation and Measurement (I&M) Society. The SCOPT comprises an international group of electronics engineers, mathematicians, and physicists with representatives from national metrology laboratories, national science laboratories, academia, and electronic industries (semiconductor, computing, telecommunication, test instrumentation, and so forth).

This standard facilitates accurate and precise communication concerning parameters of transition, pulse, and related waveforms, and the techniques and procedures for measuring them. Because of the broad applicability of electrical pulse technology in the electronics industries (such as computer, telecommunication, and test-instrumentation industries), the development of unambiguous definitions for pulse terms, and the presentation of methods and/or algorithms for their calculation is important for communication between manufacturers and consumers within the electronics industry. The availability of standard terms, definitions, and methods for their computation helps improve the quality of products and helps the consumer better compare the performance of different products. Improvements to digital waveform recorders have facilitated the capture, sharing, and processing of waveforms. Frequently these waveform recorders have the ability to process the waveform internally and provide pulse parameters. This process is done automatically and without operator intervention. Consequently, a standard is needed so that the definitions and methods of computation for pulse parameters are consistent.

The purpose of this revision was to update terminology, correct errors in the previous revision, and add a newly developed method for computing state levels. A Project Authorization Request (PAR) was submitted to the IEEE Standards Board in March 2008 to develop this revision. The PAR was approved on 19 May 2008.

History

Between 1996 and 2003, the SCOPT prepared a revision to the now withdrawn IEEE Std 181-1977, Standard on Pulse Measurement and Analysis by Objective Techniques, and withdrawn IEEE Std 194^{TM,b}-1977, Standard Pulse Terms and Definitions. These standards dealt with terms and definitions for describing and computing waveform parameters and for describing the waveform measurement process. IEEE Std 181-2003 combined the information of and superseded IEEE Std 181-1977 and IEEE Std 194-1977, both of which were withdrawn. IEEE Std 181-1977 superseded IEEE Std 181-1955. Information about IEEE Std 181-1955 and the history of the development of IEEE Std 181-1977 is located in the Foreword of the latter. The IEEE Std 194-1977 superseded IEEE Std 194-1951, IEEE Standard on Pulses: Definition of Terms—Part 1. Information about IEEE Std 194-1951 is also located in the Foreword of IEEE Std 194-1977.

The work that resulted in IEEE Std 181-2003 began in September 1996, when SCOPT submitted a PAR to the IEEE Standards Board to combine IEEE standards 181 and 194 into a single document and revise the subsequently merged document. The PAR was approved on 11 December 1996 and work on the revised and combined draft began in February 1997. The PAR expiration date was December 2002. Because of delays, SCOPT and TC-10 received approval from the IEEE for a one-year extension to enable balloting and revision as required. The draft went through several major revisions that resulted in IEEE Std 181-2003.

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Other than the merger of the two withdrawn standards, IEEE Std 181-1977 and IEEE Std 194-1977, respectively, the two major changes to the content of the standard were in the parameter definitions and algorithms. Changes to the definitions included the addition of new terms and definitions, deleting unused terms and definitions, expanding the list of deprecated terms, and updating and modifying existing definitions. This standard contains definitions for approximately 100 terms commonly used to describe the waveform measurement and analysis process and waveform parameters. Many of the terms in the 1977 versions of these standards have been deleted entirely or deprecated. Deprecated terms were kept in the standard to provide continuity between this and the withdrawn standards. Terms are deprecated whenever they cannot be defined unambiguously or precisely. Terms that were deleted had to do with signal shaping terminology and pulsed radio frequency signals, which were not within the scope of the standard, as determined by SCOPT. Development of a set of agreed-upon terms and definitions presented the greatest difficulty because of the pervasive misuse, misrepresentation, and misunderstanding of terms. Legacy issues for instrumentation manufacturers and terms of common use also had to be addressed.

These revisions also resulted in the development of algorithms for computing the values of certain waveform parameters in all cases where these algorithms could be useful or instructive to the user of the standard. The intention of the SCOPT in adding these algorithms, which are recommended for use, was to provide industry with a common and communicable reference for these parameters and their computation. Heretofore, this was not available and there existed much debate and misunderstanding between various groups measuring the same parameters. Similarly, this is the reason the SCOPT decided to add several examples of basic waveforms, with formulae. The SCOPT focused these algorithms on the analysis of two-state, single-transition waveforms. The analysis of compound waveforms (waveforms with two or more states and/or two or more transitions) is accomplished by first decomposing the compound waveform into its constituent two-state, single-transition waveforms. A method for performing this decomposition is provided.

Algorithms for the analysis of fluctuation and random jitter of waveforms were also introduced into the standard. These algorithms describe the computation of the mean and standard deviation of jitter and fluctuation. The standard also contains methods to estimate the accuracy of the standard deviation and to correct its value.

The SCOPT added Annex A into this standard, which contains numerous figures depicting different types of waveforms. These waveform examples, with the associated expressions used to generate them, help the reader understand the use of certain defined terms and provide a common ground for communicating waveform types and how they can be computed.

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IEEE Standard ~~on~~for Transitions, Pulses, and Related Waveforms

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1. Overview

1.1 Scope

This standard ~~provides definitions of~~ defines terms pertaining to transitions, pulses, and related waveforms and ~~provides definitions and descriptions of techniques and~~ defines procedures for ~~measuring~~ estimating their parameters.

1.2 Purpose

The ~~waveforms considered in this purpose of the~~ standard ~~are those that make a number of transitions and that remain relatively constant in the time intervals between transitions~~ is to unambiguously and accurately define terms pertaining to transitions, pulses, and related waveforms and the algorithm for their computation. This helps to communicate requirements between vendors and users, improves understanding and readability of instrument performance specifications, and provides a common ground for parameter and performance comparisons.

2. Normative references

The following referenced documents are indispensable for the application of this document (i.e., they must be understood and used, so each referenced document is cited in text and its relationship to this document is explained). For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments or corrigenda) applies.

ISO/IEC Guide 98-3:2008, Uncertainty of measurement—Part 3: Guide to the expression of uncertainty in measurement (GUM).¹

[ISO/IEC Guide 99:2007, International Vocabulary of Metrology—Basic and general concepts and associated terms \(VIM\).](#)

[ISO 10012:2003, Measurement management systems—Requirements for measurement processes and measuring equipment.](#)

3. Definitions, symbols and deprecated terms

3.1 Definitions

[For the purposes of this document, the following terms and definitions apply. The *IEEE Standards Dictionary: Glossary of Terms & Definitions*² and ISO/IEC Guide 99:2007 should be referenced for terms not defined in this clause.](#)

1.2 Object

~~The object of this standard is to facilitate accurate and precise communication concerning parameters of transitions, pulses, and related waveforms and the techniques and procedures for measuring them.~~

1.3 Deprecated terms

Along with the recommended terms and their definitions, ~~Clause 3 of this standard also contains~~ a number of deprecated but widely used terms. ~~These deprecated terms and the reason are listed in 3.3. The reasons for their deprecation are given~~[noted](#) after the definition of the recommended term. [All defined terms are italicized in this document.](#)

1.4 Representations and conventions

Throughout this standard, time is ~~taken to be~~ an independent variable, symbolized with the letter *t*. *Waveform* value is used to refer to the dependent variable, symbolized by *y(t)*. For particular waveforms, *waveform* value will be synonymous with terms such as *voltage*, *current*, *power*, or some other quantity.

2. References

~~This standard shall be used in conjunction with the following publications. When the following specifications are superseded by an approved revision, the revision shall apply.~~

~~ISO Guide to the Expression of Uncertainty in Measurement, rev. 1993, ISBN 92-67-10188-9.¹~~

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aberration region

aberration region, ~~pre~~ post-transition: The *interval* between a user-specified *instant* and a fixed *instant*, where the fixed *instant* is the first sampling *instant* succeeding the 50% reference level *instant* ~~when for which the~~ [corresponding waveform value is within the state boundaries of the state succeeding the 50% reference level instant.](#)

The user-specified *instant* occurs after the fixed *instant* and is typically equal to the fixed *instant* plus three times the *transition duration*.

aberration region, pre-transition: The *interval* between a user-specified *instant* and a fixed *instant*, where the fixed *instant* is the first sampling instant preceding the 50% reference level instant for which the corresponding waveform value is within the state boundaries of the state preceding the 50% reference level instant. The user-specified *instant* occurs before the fixed *instant* and is typically equal to the fixed *instant* minus three times the *transition duration*.

accuracy: The closeness of agreement between the result of a measurement and the true value of the measurand.

¹ISO IEC publications are available from the ISO Central Secretariat, Case Postale 56, 1 rue de Varembe, CH-1211, Genève 20, Switzerland/Suisse (<http://www.iso.ch/>). ISO/IEC publications are also available from the American National Standards Institute, 25 West 43rd Street, 4th Floor, New York, NY 10036 (<http://ansi.org/>).

²The IEEE Standards Dictionary: Glossary of Terms & Definitions is available at <http://shop.ieee.org/>.

amplitude

amplitude, impulse: The difference between the specified *level* corresponding to the *maximum peak* (*minimum peak*) of the positive (negative) *impulse-like waveform* and the level of the state preceding the first *transition* of that *impulse-like waveform*.

amplitude, waveform: The difference between the *levels* of two different *states* of a *waveform*. Two different definitions for *amplitude* are authorized by this standard because they are both in common use. In all applications of this standard, the chosen definition shall be clearly identified. The two definitions are as follows:

amplitude, waveform, signed: The *level* of the *state* succeeding a *transition* minus the *level* of the *state* preceding the same *transition*.

amplitude, waveform, unsigned: The absolute value of the *signed amplitude*.

correction: This operation combines the results of the conversion operation ~~(see 4.2)~~ with the transfer function information to yield a *waveform* that is a more accurate representation of the *signal*. *Correction* shall be performed to an *accuracy* that is consistent with the overall *accuracy* desired in the *waveform measurement process*.

NOTE—*Correction* may be effected by a manual process by an operator, a computational process, or a compensating device or apparatus. See 4.1.³

cycle: A portion of a *periodic waveform* with a *duration* of one *period*.

delaying: A process in which a *signal* is ~~delayed~~ caused to occur later in time.

differentiation: A shaping process in which a *waveform* is converted to a *waveform* whose shape is, or approximates, the time derivative of that *waveform*.

duration: The difference between two specified *instants*.

duty factor: Unless otherwise specified, for a *periodic pulse train*, the ratio of the *pulse duration* to the *waveform period*.

NOTE—The ~~following is a deprecated term: duty cycle. The term duty cycle is a deprecated term~~ because the word *cycle* in this standard refers to the *period* of a *signal*.

fluctuation: Variation (dispersion) of a *level* parameter of a set of *repetitive waveforms* with respect to a ~~reference amplitude or a reference level. Unless otherwise specified by a mathematical adjective, root-mean-square (rms) fluctuation is assumed.~~
reference amplitude or a reference level.

NOTE—Unless otherwise specified by a mathematical adjective, *rms fluctuation* is assumed.

frequency: The reciprocal of *waveform period*.

glitch: A *transient* that leaves an *initial state*, enters the *boundaries* of another *state* for a *duration* less than the *duration* for *state occurrence*, and then returns to the *initial state*.

instant: ~~Unless~~ A particular time value within a waveform epoch that, unless otherwise ~~specified, a time specified with respect specified, is referenced relative~~ to the *initial instant*, ~~t_0~~ , of that *waveform epoch*.

instant, final: The last sample instant in the waveform.

instant, impulse center: The instant at which a user-specified approximation to the *maximum peak* (*minimum peak*) of the positive (negative) *impulse-like waveform* occurs.

³Notes in text, tables, and figures of a standard are given for information only and do not contain requirements needed to implement this standard.

~~3.1.13.2 instant, impulse center: The instant at which a user specified approximation to the maximum peak (minimum peak) of the positive (negative) impulse-like waveform occurs.~~

instant, initial: The first sample *instant* in the *waveform*.

instant, pulse center: The average of the two *instants* used to calculate the *pulse duration*.

instant, reference level: An *instant* at which the *waveform* intersects a specified *reference level*.

instant, transition occurrence: The first 50% *reference level instant* ~~(see 5.3.3.1)~~, unless otherwise specified, on the *transition* of a *step-like waveform*.

NOTE—See 5.3.3.1 and Figure 2 through Figure 3, Figure 4, Figure 5, and Figure 6.6.

integration: A *shaping process* in which a *waveform* is converted to a *waveform* whose shape is or approximates the *time integral* of that *waveform*.

interval: The set of all values of time between a first instant and a second *instant*, where the second *instant* is later in time than the first.

NOTE—These first and second instants ~~referred to~~ are called the endpoints of the *interval*. The endpoints,

unless otherwise specified, are assumed to be part of the *interval*.

jitter: The variation (dispersion) of a time parameter between successive *cycles* of a *repetitive signal* and/or between successively acquired *waveforms* of a *repetitive signal* for a given reference [level](#) instant or duration.

[NOTE—Unless otherwise specified by a mathematical adjective, rms jitter is assumed.](#)

jitter, cycle-to-nth-cycle: The *jitter* between specified *reference level instants* of any two specified *cycles* of a *repetitive signal*.

jitter, period: The *jitter* in the *period* of a *repetitive signal* or its *waveform*.

jitter, pulse duration: The *jitter* in the *pulse duration* of a *signal* or its *waveform*.

jitter, trigger: The *jitter* between a *repetitive signal* and the trigger event that is used to generate or measure that *signal*.

level: Constant value, ~~such~~ [having the same units](#) as ~~a de-voltage~~ *y*.

level, average: Pertaining to the value of the mean of the *waveform level*. If the *waveform* takes on *n* discrete values, y_j , all equally spaced in time, the *average level* is,

$$\bar{y} = \left(\frac{1}{n} \right) \sum_{j=1}^n y_j$$

If the *waveform* is a continuous function of time $y(t)$,

$$\bar{y} = \left(\frac{1}{t_2 - t_1} \right) \int_{t_1}^{t_2} y(t) dt$$

The summation or integral extends over the *waveform epoch* for which the *average level* is desired or, if the function is *periodic*, over any integral number of *periodic* repetitions of the function.

level, average absolute: Pertaining to the mean of the absolute *waveform* value. If the *waveform* takes on *n* discrete values y_j , all equally spaced in time, the *average absolute level* is,

$$\overline{|y|} = \left(\frac{1}{n} \right) \sum_{j=1}^n |y_j|$$

If the *waveform* is a continuous function of time $y(t)$,

$$\overline{|y|} = \left(\frac{1}{t_2 - t_1} \right) \int_{t_1}^{t_2} |y(t)| dt$$

The summation or the integral extends over the *waveform epoch* for which the *average absolute level* is desired or, if the function is *periodic*, over any integral number of *periodic* repetitions of the function.

level, percent reference: A *reference level* specified by:

$$y_{x\%} = y_{0\%} + \frac{x}{100}(y_{100\%} - y_{0\%})$$

where

$$0\% < x < 100\%$$

$y_{0\%}$ is the *level of low state*

$y_{100\%}$ is the *level of high state*

$y_{0\%}$, $y_{100\%}$, and $y_{x\%}$ are all in the same unit of measurement.

NOTE 1—Commonly used reference levels are: 0%, 10%, 50%, 90%, and 100%. **NOTE 2**—See Figure 2, ~~Figure 3, Figure 4, and through~~ Figure 5.

level, reference: A user specified *level* that extends through all *instants* of the *waveform epoch*.

NOTE—~~The following are deprecated terms: mesial, proximal, and distal. Mesial, proximal, and distal~~ lines are deprecated terms because (1) line refers to consideration of and computations using a *pictorial waveform representation*, whereas *waveforms* today are primarily stored in *digital waveform representations* and computation and viewing are done using a computer; ~~(2) the terms mesial, proximal, and distal~~ (2) they refer to user-defined *reference levels*, and it is not necessary to have redundant definitions for these *reference levels*; and (3) the terms *proximal* and *distal* cannot be used unambiguously to describe lines or points on either side of a *transition* of a *step-like waveform* because they depend on whether the *step-like waveform* is for a *positive pulse* or a *negative pulse*. In other words, ~~for (3),~~ the proximal line and points if referenced to the 10% *reference level*, will appear to the left of a *transition* for a *positive pulse* and to the right for a *negative pulse*.

level, root-mean-square (rms): Pertaining to the value of the square root of the average of the squares of the *waveform* values. If the *waveform* takes on n discrete values y_j , all equally spaced in time, the *rms level* is,

$$y_{\text{rms}} = \sqrt{\left(\frac{1}{n}\right) \sum_{j=1}^n y_j^2}$$

If the *waveform* is a continuous function of time $y(t)$,

$$y_{\text{rms}} = \sqrt{\left(\frac{1}{t_2 - t_1}\right) \int_{t_1}^{t_2} y^2(t) dt}$$

The summation or the integral extends over the *waveform epoch* for which the *rms level* is desired or, if the function is *periodic*, over any integral number of *periodic* repetitions of the function.

level, root sum of squares (rss): Pertaining to the value of the square root of the arithmetic sum of the squares

of the *waveform values*. If the *waveform* takes on n discrete values y_j , all equally spaced in time, the *rss level* is,

$$y_{\text{rss}} = \sqrt{\sum_{j=1}^n y_j^2}$$

If the *waveform* is a continuous function of time $y(t)$,

$$y_{\text{rss}} = \sqrt{\int_{t_1}^{t_2} y^2(t) dt}$$

The summation or the integral extends over the *waveform epoch* for which the ~~rss~~[root sum of squares](#) level is desired.

3.1.18 maximum (minimum) peak: ~~Pertaining to the greatest (least) value of the waveform.~~

offset: The algebraic difference between two specified *levels*. Unless otherwise specified, the two *levels* are *state 1* and the *base state*.

NOTE—See Figure 2 through Figure 5.

overshoot: A *waveform aberration* within a *post-transition aberration region* or *pre-transition aberration region* that is greater than the *upper state boundary* for the associated *state level*.

[NOTE 1—If more than one such waveform aberration exists, the one with the largest magnitude is the overshoot unless otherwise specified.](#)

[NOTE 2—See Figure 9 and Figure 10.](#)

parameter: Any value (number multiplied by a unit of measure) that can be calculated from a *waveform*.

parameter, level: A *parameter* whose units are the same as the units of *levels*.

parameter, time: A *parameter* whose units are a unit of time.

[peak, maximum \(minimum\):](#) Pertaining to the greatest (least) value of the waveform.

peak-to-peak: Pertaining to the value of the difference between the extrema of the specified *waveform*.

periodic (aperiodic): Having the properties of a *periodic (aperiodic)* function.

precision: The degree of agreement between independent measurements of the same parameter.

pulse duration: The difference between the first and second *transition occurrence instants*.

NOTE 1—See Figure 4 and Figure 5.

NOTE 2— ~~The following is a deprecated term: pulse width.~~ Pulse width, as well as full width at half maximum (FWHM) and half width at half maximum (HWHM) are, in general, deprecated terms, because *width* is a word that denotes a spatial parameter whereas the parameter of interest is time. However, in some applications, it may be desirable to discuss the spatial location of a propagating pulse and its spatial distribution, i.e., *pulse*

width in matter or space. FWHM, HWHM, and *full duration at half maximum* (FDHM) are deprecated terms because of the reference to the maximum value of the *waveform*, where the *waveform amplitude* may be either positive or negative and the *waveform* may contain noise.

pulse separation: The *duration* between the 50% *reference level instant*, unless otherwise specified, of the second *transition* of one *pulse* in a *pulse train* and that of the first *transition* of the immediately following *pulse* in the same *pulse train*.

pulse train: A *repetitive* sequence of *pulse waveforms*. Unless otherwise specified, all of the *pulse waveforms* in the sequence are assumed to be identical.

NOTE—See Figure A.12.

pulse waveform: A *waveform* whose *level* departs from one *state*, attains another *state*, and ultimately returns to the original *state*.

NOTE 1—As defined here, a pulse waveform consists of two *transitions* and two *states* ~~(see Clause 4)~~. Alternatively, a *pulse waveform* can be described as a *compound waveform* consisting of the sum of a positive (negative) *step-like waveform* and a *delayed negative* (positive) *step-like waveform* both having the same *unsigned waveform amplitude*.

NOTE 2—*Leading edge* and *trailing edge* are deprecated terms because 1) the word *edge* describes the property of a geometric figure, which is not contained by or representative of the physical signal that corresponds to the *waveform*, and 2) the terms *first* and *second* adequately and unambiguously describe the meanings of *leading* and *trailing*.

NOTE 3—See Figure 4 and Figure 5.

pulse waveform, negative: A pulse waveform whose first transition is a negative-going transition.

NOTE—See Figure 5.

pulse waveform, positive: A pulse waveform whose first transition is a positive-going transition.

NOTE—See Figure 4.

reference: Of or pertaining to a time, *level*, *waveform feature*, or *waveform* that is used for comparison with, or evaluation of, other times, *levels*, *waveform features*, or *waveforms*. ~~A reference~~ This type of entity may, or may not, be an ideal entity.

repetitive (nonrepetitive): Of or pertaining to a series of specified *waveform features* or *waveforms* that repeat or recur (do not repeat or recur) in time.

resolution: The smallest distinguishable increment into which a measured quantity is divided.

ringing: An *aberration* in the form of a superimposed oscillatory *waveform* that, when present, usually follows a *transition*.

runt: A *transient* that leaves an initial *state*, does not attain the *level* of another *state*, and returns to the initial state.

sampling: A process of ~~measuring~~ determining representative *levels* at selected *instants* of a *waveform* for the purpose of determining parameters or characteristics of the whole *waveform*.

signal: A physical phenomenon that is a function of time and space.

spike: A *transient* that leaves an initial *state*, exceeds the farthest *state boundary* of any other *state*, and returns to the initial *state*.

state: A particular *level* or, when applicable, a particular level with an associated and upper and lower limits (the upper and lower state boundaries) that are referenced to or associated with that *level*.

NOTE 1—Unless otherwise specified, multiple *states* are ordered from the most negative *level* to the most positive *level*, and the *state levels* are not allowed to overlap. The most negative *state* is called *state 1*. The most positive *state* is called *state n*. The *states* are denoted by $s_1, s_2, \dots, s_n$; the *state levels* are denoted by $\text{level}(s_1), \text{level}(s_2), \dots, \text{level}(s_n)$; the upper *state boundaries* are denoted by $\text{upper}(s_1), \text{upper}(s_2), \dots, \text{upper}(s_n)$; and the lower *state boundaries* are denoted by $\text{lower}(s_1), \text{lower}(s_2), \dots, \text{lower}(s_n)$.

NOTE 2—*States, levels, and state boundaries* are defined to accommodate pulse metrology and digital applications. In pulse metrology, the *levels* of a *waveform* are measured and *states* (with or without associated *state boundaries*) are then associated with those *levels*. In digital applications, *states* are defined (with *state boundaries*) and the *waveform* values are determined to either lie within a *state* or not.

state, base: The ~~base-state of a step-like-waveform is a user specified state~~ that, unless otherwise specified, ~~is the state that~~ possesses a *level* closest to zero.

NOTE—See Figure 2 through Figure 6.

state, high: The most positive *state* within the *waveform epoch*, unless otherwise specified.

NOTE—For *waveforms* with exactly two *states*, such as the single *transition waveform*, the terms *low state* and *high state* may be used in lieu of the terms *state 1* and *state 2*, respectively.

state, low: ~~the low state of a waveform is the~~ The most negative *state* within the *waveform epoch*, unless otherwise specified.

NOTE—For *waveforms* with exactly two *states*, such as the single *transition waveform*, the terms *low state* and *high state* may be used in lieu of the terms *state 1* and *state 2*, respectively.

state, positive (negative): A *state* whose *level* is greater (less) than zero.

state boundaries: The upper and lower limits of the *states* of a *waveform*. All values of a *waveform* that are within the boundaries of a given *state* are said to be in that *state*. ~~The state boundaries are defined by the user.~~

NOTE—The *state boundaries* are defined by the user.

state occurrence: A contiguous region of a *waveform* that is bounded by the upper and lower *state boundaries* of a *state*, and whose *duration* equals or exceeds the specified minimum *duration* for *state attainment*.

NOTE—The *state occurrence* consists of the entire portion of the *waveform* that remains within the boundaries of that *state*. *State occurrences* are numbered as ordered pairs (s, n) , where s_i refers to the i th *state*, and n is the number of the occurrence of that particular *state* within the *waveform epoch*. In a given *waveform epoch*, when the *waveform* first enters a *state*, s_1 , that *state occurrence* is $(s_1, 1)$. If and when the *waveform* exits that *state*, that *state occurrence* is over. If and when the *waveform* next enters and remains in *state* s_1 , that *state occurrence* would be labeled $(s_1, 2)$; and so on. Thus, the state occurrences for a single pulse (see Figure 4 and Figure 6) are $(s_1, 1), (s_2, 1), (s_1, 2)$. The state occurrences for the compound waveform (see Figure 6) are $(s_2, 1), (s_4,$

1), (s3, 1), (s5, 1), (s1, 1). Note that a *waveform* can exit one *state occurrence* without (necessarily) immediately entering another *state occurrence*. That is, the *waveform state* between *state occurrences* can be undefined for some time interval, for example, during *transitions* and in the case of *transients* (such as, *runt pulses*).

synchronizing: The process of aligning the *transition occurrence instant* of one *pulse* or other event with the *transition occurrence instant* of another *pulse* or event. If two series of events, such as two *pulse trains*, are synchronized, then their *periods* shall be integer multiples of one another.

terminal feature: Any contiguous region of a *waveform* that is neither a *state occurrence*, nor a *transient*, nor a *transition*. This feature, if present, occurs only at the beginning and/or end of a *waveform*.

tilt: A distortion of a *waveform state* wherein the overall slope over the extent of the *waveform state* is essentially constant and other than zero. ~~This distortion~~ This distortion may be of either polarity.

NOTE—The term *droop* is ~~a~~ deprecated because it implies a negative slope and, therefore, cannot be applied unambiguously to both *positive pulse waveforms* and *negative pulse waveforms*.

transient: Any contiguous region of a *waveform* that begins at one *state*, leaves and subsequently returns to that *state*, and contains no *state occurrences*.

transition: Contiguous region of a *waveform* that connects, either directly or via intervening transients, two *state occurrences* that are consecutive in time but are occurrences of different *states*.

transition, negative-going: A *transition* whose terminating *state* is more negative than its originating *state*.

NOTE 1— The endpoints of the *negative-going transition* are the last exit of the *waveform* from the higher *state boundary* and the first entry of the *waveform* into the lower *state boundary*.

NOTE 2— The term *falling edge* is deprecated because 1) the word *edge* describes the property of a geometric figure, which is not contained by, or representative of, the physical signal that corresponds to the *waveform*, and 2) the word *falling* refers to motion or position of physical objects.

transition, pass through: The *transition* from an initial *state* to a nonconsecutive *state* through any number of other *states* where the *duration* in these other *states* is less than the *duration* for *state occurrence*.

transition, positive-going: A *transition* whose terminating *state* is more positive than its originating *state*.

NOTE 1— The endpoints of the *positive-going transition* are the last exit of the *waveform* from the lower *state boundary* and the first entry of the *waveform* into the higher *state boundary*.

NOTE 2— The term *rising edge* is deprecated because) the word *edge* describes the property of a geometric figure, which is not contained by, or representative of, the physical signal that corresponds to the *waveform*, and 2) the term *rising* refers to motion or position of physical objects.

transition duration: The difference between the two *reference level instants* of the same *transition*. Unless otherwise specified, the two *reference levels* are the 10% and 90% *reference levels*.

NOTE 1—See Figure 2 and Figure 3.

NOTE 2—The following terms are deprecated: *risetime* (~~rise time~~), *falltime* (~~fall time~~), *leading edge*, *rising edge*, *trailing edge*, *falling edge*, and *transition-time*. The terms *risetime*, *falltime*, and *transition time*, although widely used, are deprecated because they are ambiguous and confusing. First, the use of the word *time* in this standard refers exclusively to an *instant* and not an *interval*. Also, if the first transition of a *waveform* within a *waveform epoch* happens to be a *negative-going transition*, some users may refer to its *transition duration* as its *risetime*, and some others may refer to its *transition duration* as its *falltime*. If the use of these deprecated terms is required,

then *risetime* is synonymous with the *transition duration* of a *positive-going transition*, and *falltime* is synonymous with the *transition duration* of a *negative-going transition*. If the *upper* and *lower state boundaries* of the two *states* are not the user-defined *reference levels* (for example, the 10% and 90% *reference levels*), then the *duration* of a *transition* is not equal to the *transition duration*.

transition settling duration: The time interval between the 50% *reference level instant*, unless otherwise specified, and the final *instant* the *waveform* crosses the *state boundary* of a specified *state* in its approach to that *state*.

NOTE—The ~~following is a deprecated~~ term *settling time*. ~~The term settling time is a deprecated term~~ because the word *time* in this standard refers exclusively to an *instant* and not an *interval*.

transition settling error: The maximum error between the *waveform* value and a specified *reference level* within a user-specified *interval* of the *waveform epoch*. The *interval* starts at a user-specified *instant* relative to the 50% *reference level instant*.

triggering: A process in which a *step-like waveform signal*, pulse, or *compound* signal initiates a predetermined event or response.

undershoot: A *waveform aberration* within a *post-transition aberration region* or *pre-transition aberration region* that is less than the *lower state boundary* for the associated *state level*.

NOTE 1—If more than one such waveform aberration exists, the one with the largest magnitude is the undershoot unless otherwise specified.

NOTE 2—See Figure 9 and Figure 10.

NOTE 3—The term *preshoot* is deprecated because the prefix, *pre*,” is temporal and the root word, *shoot*, in this context, refers to a *level parameter*.

waveform: A representation of a *signal* (for example, a graph, plot, oscilloscope presentation, discrete time series, equations, or table of values). ~~Note that the This term waveform~~ refers to a measured or otherwise-defined estimate of the physical phenomenon or *signal*.

NOTE—See Figure 2 through Figure 6, and the figures in Annex A.

waveform, compound: A *waveform* that may be completely represented by *m states* and *n transitions* where $(m + n) \geq 4$.

NOTE 1—See Figure 6.

NOTE 2—Any compound waveform can be parsed (see 5.5) into *n* two-state waveforms.

waveform, impulse-like: A *waveform* that, when convolved with an ideal step, yields a *step-like waveform*.

NOTE—See Figure 6.

waveform, reference: A *waveform* against which other *waveforms* are compared.

NOTE—Annex A contains figures that depict different reference waveforms.

waveform, step-like: A *waveform* whose *level* departs from one *state* and attains another *state*.

NOTE 1—Unless otherwise specified, multiple transitions are ordered from the earliest transition occurrence *instant* to the latest occurrence in time.

NOTE 2—See Figure 2 and Figure 3.

waveform, transition: A *waveform* consisting of a *transition* and the two *states* joined by that *transition*.

waveform aberration: The algebraic difference in *waveform* values between all corresponding *instants* in time of a *waveform* and a *reference waveform* in a specified *waveform epoch*.

NOTE—See Figure 8.

waveform aberration, percent: For a two-state *waveform*, ~~the waveform aberration~~ this is expressed as a percentage of the *waveform amplitude* of the *reference waveform*, unless otherwise specified.

NOTE—Compound waveforms may be parsed (see 5.5) into a set of two-state waveforms after which percent *waveform aberration* may be defined for each two-state *waveform* of that set.

waveform delay (advance): The ~~waveform delay is the~~ duration between the first *transition occurrence instant* of two *waveforms*.

waveform epoch: An *interval* to which consideration of a *waveform* is restricted for a particular calculation, procedure, or discussion. Except when otherwise ~~specified, the waveform epoch~~ specified, it is assumed to be the span over which the *waveform* is measured or defined.

NOTE—See Figure 2 through Figure 5.

waveform feature: A specified portion or segment of a *waveform*.

waveform measurement process: A realization of a method of ~~waveform~~ measurement in terms of specific devices, apparatus, instruments, auxiliary equipment, conditions, operators, and observers. In this process, a value (a number multiplied by a unit) of measurement is assigned to the elements of the *waveform*.

waveform period: The minimum *duration* after which a *periodic waveform* repeats. The period of a *repetitive two-state waveform* is the *duration* between specified *reference level instants* for the same *transition*, either the *negative-going transition* or the *positive-going transition*, of two consecutive *pulses* in a *pulse train*. The period is equal to the sum of the *pulse separation* and the *pulse duration*.

waveform representation: ~~(See 3.1.47.1 through 3.1.47.4.)~~

waveform representation, pictorial: A pictorial format is a graph, plot, or display in which a *waveform* is presented for observation or analysis.

NOTE—Any of the *waveform* formats defined in the subclauses to follow may be presented in the pictorial format.

waveform representation, sampled: A sampled format is a *waveform* that is a series of *sample* numerical values taken sequentially or nonsequentially as a function of time. It is assumed that nonsequential samples may be rearranged in time sequence to yield the ~~aperiodically~~ following sampled formats: ~~waveform representation and the periodically sampled waveform representation~~

waveform representation, sampled, aperiodically: A format that is identical to the *periodically sampled format*, above, except that the sampling in real time is not *periodic* and wherein the data exists as coordinate *instant* pairs, $t_1, y_1; t_2, y_2; \dots; t_n, y_n$.

waveform representation, sampled, periodically: A finite sequence of *levels* $y_0, y_1, y_2, \dots, y_n$ each of which represents the value of the *waveform* at times $t_0, t_0 + \Delta t, t_0 + 2\Delta t, \dots, t_0 + n\Delta t$, respectively, wherein the data may exist in a pictorial format or as a list or table of numbers.

3.2 Symbols

A waveform amplitude

df duty factor

i discrete time index

n number of elements in a *waveform*

O_{post} overshoot in the *post-transition aberration region* of a *waveform*

O_{pre} overshoot in the *pre-transition aberration region* of a *waveform*

s_k state level k

t continuous time

$t_{x\%}$ $x\%$ reference level instant

t_0 initial instant

T waveform period

t_d transition duration

T_D waveform delay

T_p pulse duration

T_s pulse separation

U_{post} undershoot in the *post-transition aberration region* of a *waveform*

U_{pre} undershoot in the *pre-transition aberration region* of a *waveform*

W_a waveform aberration, given as percentage of waveform amplitude

$y(t)$ waveform amplitude values for a continuous-time signal

y_i waveform amplitude values for a discrete-time *waveform*, with discrete time index i

y_{rms} rms level ~~(see 3.1.17.5)~~

y_{rss} rss level ~~(see 3.1.17.6)~~

$y_{x\%}$ $x\%$ reference level

y average level ~~(see 3.1.17.1)~~

y_i mean over a collection of *waveforms* $y_{k,i}$, where k is the *waveform* index

Σ_i the standard deviation of a set of standard deviations

3.3 Deprecated terms

Deprecated terms are listed below in the left-hand column, in alphabetical order, and the terms on the right are the accepted terms.

Droop	<i>tilt</i>
Duty cycle	<i>duty factor</i>
Falling edge	<u>negative-going transition</u> ~~transition duration~~
Falltime <u>(Fall time)</u>	<i>transition duration</i>
Leading edge	<u>first</u> ~~transition duration~~
Preshoot	<i>overshoot or undershoot in the pre-transition aberration region</i>
Pulse width	<i>pulse duration</i>
Risetime <u>(Rise time)</u>	<i>transition duration</i>
Rising edge	<u>positive-going</u> ~~transition duration~~
~~settling time~~	~~transition settling duration~~
Trailing edge	<u>second transition</u>
Transition ~~time~~	<i>transition duration</i>

[NOTE—The word *transition* is deprecated when used to refer to an interval within a waveform epoch but when referring to an event, as defined in 3.1, it is not deprecated.](#)

4. Measurement and analysis techniques

[4.1 Descriptions of techniques and procedures](#)

This subclause provides descriptions of the techniques and procedures for time-domain waveform measurements. The descriptions provided are independent of specific devices, apparatus, instruments, or computing devices that may be used in these measurements and are prerequisite to the following:

- Efficient communication of the results of *transition*, *pulse*, and *compound waveform* measurements
- Development and use of physical artifact standards for *transition*, *pulse*, and *compound waveform* apparatus
- Development and use of procedures for apparatus that employ *transition*, *pulse*, and *compound waveform* techniques

4.2 Method of waveform measurement

A method of making a waveform measurement comprises the following:

- The complete specification of all relevant functional characteristics of the devices, apparatus, instruments,

and auxiliary equipment to be used

- b) The [specification of all](#) essential corrections required [to compensate or adjust for departure of the measurement process from ideality](#)
- c) The procedures to be used in making essential corrections
- d) The operations to be performed and their sequence
- e) The conditions under which all operations are to be carried out

4.3 Description of the waveform measurement process

The object of any *waveform measurement process* is the determination to some accuracy, either expressed or implied, of the value of one or more *parameters* of a *waveform*. [Requirements for measurement processes are described in ISO 10012:2003](#). Figure 1 shows the constituent steps of any *waveform measurement process* where, as indicated, the process involves two distinct sequential subprocesses: [1\)](#) *signal-to-waveform* conversion, and [2\)](#) *waveform* analysis. Thus, the *waveform measurement process* involves:

- a) The conversion of a *signal* into its transform, [which is called its](#) *waveform*
- b) Analysis of the *waveform* to determine the value of one or more *parameters*
- c) The assertion or assumption that the value of the *waveform parameter* thus determined is, to some *accuracy*, identical to the value of the *signal parameter*. The validity of the final assertion or assumption is dependent on the combined validity of the first two steps.

The vast array of devices, apparatus, instruments, and techniques, which may be configured in virtually limitless combinations to provide *signal-to-waveform* conversion, renders the discussion of specific implementations beyond the scope of this standard. Such discussion is deferred to other standards, documents, or specifications that describe or define the characteristics or methods of specific devices, apparatus, instruments, or techniques.

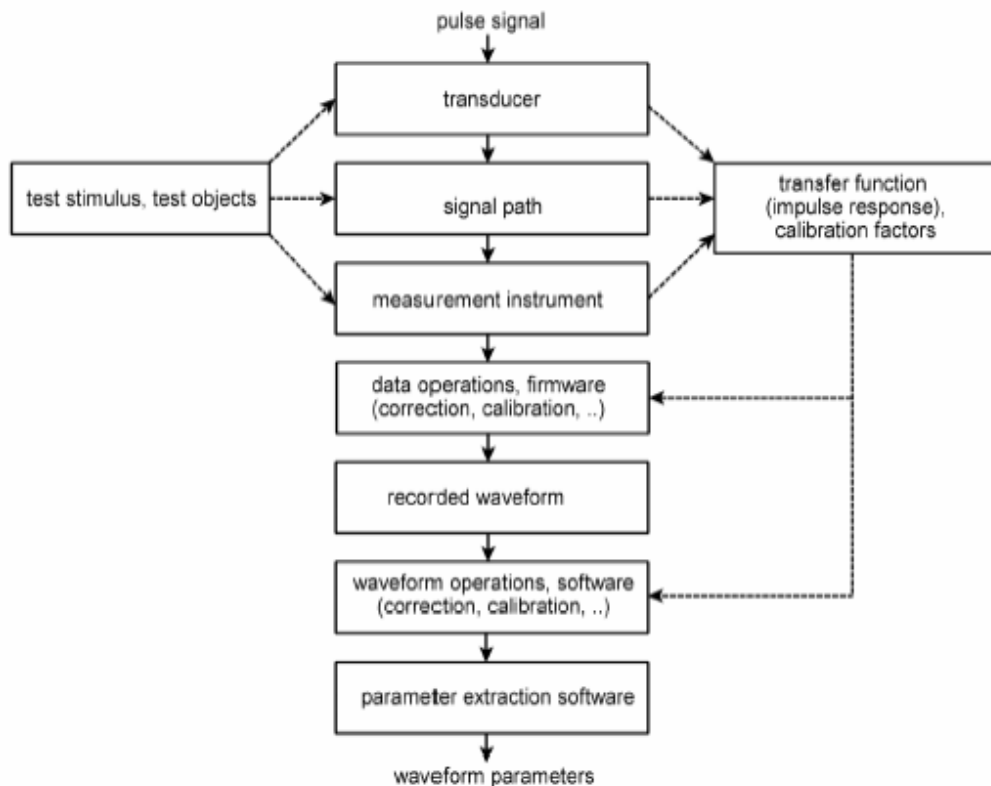


Figure 1—Waveform acquisition and measurement process

4.4 Waveform epoch determination

4.4.1 Selection of waveform epoch

A *waveform epoch* shall contain the *waveform features* under analysis. The *waveform epoch* shall contain sufficient data to yield all necessary *state levels* to the desired *accuracy* prescribed in the measurement process. These data may be augmented by *reference levels* that are determined using another *waveform epoch*.

4.4.2 Exclusion of data from analysis

A *waveform* may include *waveform features* or events that are nonpertinent in the circumstances of or to the application of the *waveform*. Nonpertinent data may be excluded from analysis; however, the basis for any such exclusion shall be stated.

When data within a *waveform epoch* are excluded from analysis, the following shall be specified:

- The extent, in time or waveform value, of the excluded data
- The basis for excluding the data