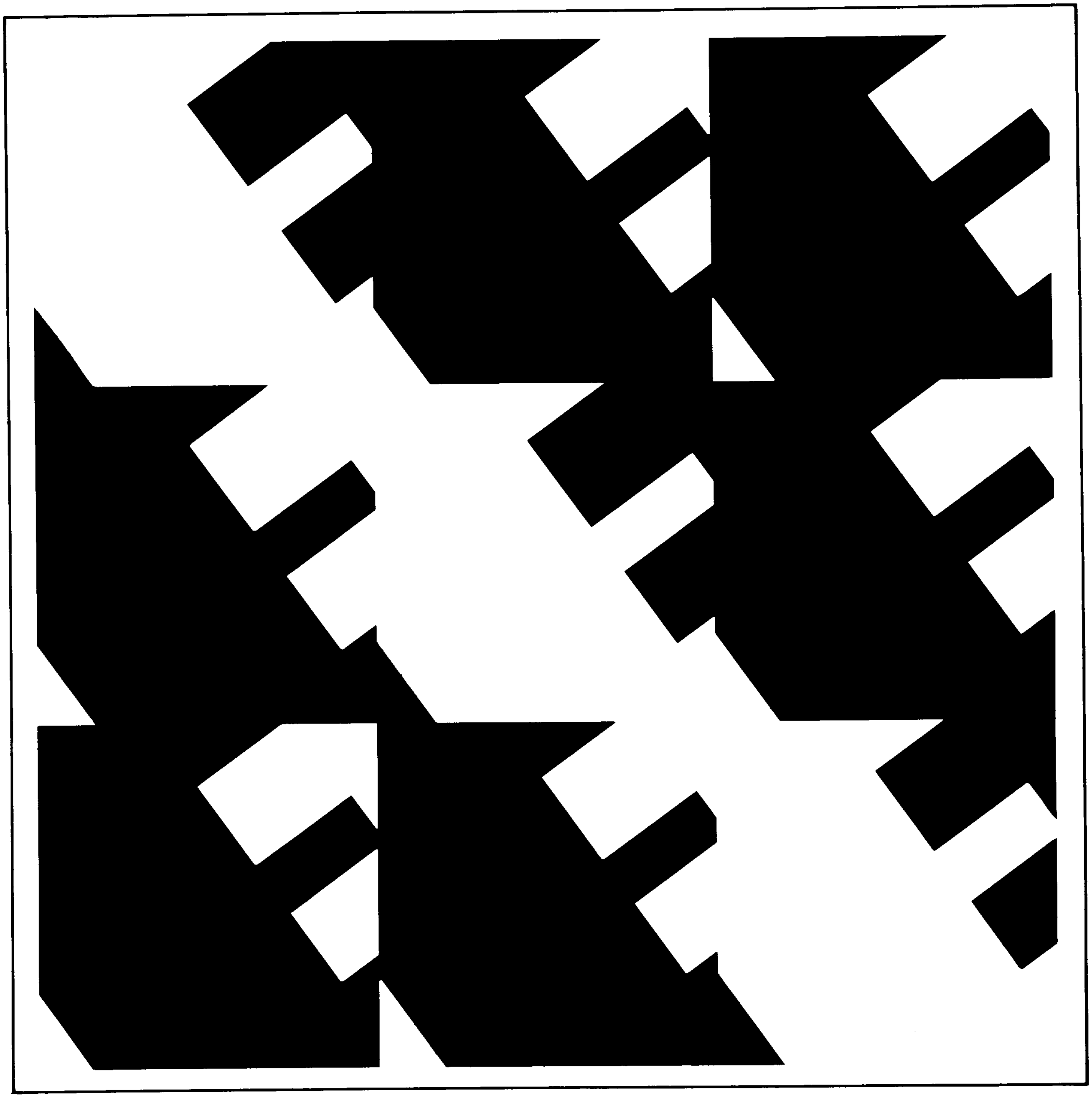
AMERICAN NATIONAL STANDARD

ANSI/IEEE Std 181-1977
(Revision of IEEE Std 181-1955)

IEEE Standard on Pulse Measurement and Analysis by Objective Techniques



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An American National Standard

IEEE Standard on Pulse Measurement and Analysis by Objective Techniques

Sponsor

High Frequency Instruments and
Measurements Committee of the
IEEE Instrumentation and Measurements Group

Approved September 4, 1975
IEEE Standards Board

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American National Standards Institute

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Foreword

(This Foreword is not part of IEEE Std 181-1977, Pulse Measurement and Analysis by Objective Techniques.)

This standard supersedes IEEE Std 181-1955, Methods of Measurement of Pulse Quantities. It should be used in conjunction with IEEE Std 194-1977, Pulse Terms and Definitions.

The previous editions of the IEEE standards on pulses were published in 1951-1955, a period when pulse measuring instruments (principally, the cathode ray oscilloscope) were completing their evolution from qualitative indicators to quantitative instruments. These previous standards reflected this evolutionary stage in nomenclature, definitions, and methods of measurement which relied heavily on visual observation and subjective evaluation, or where more exact results were desired, on planimetric techniques. No review of the growth of pulse technology in the intervening years is needed here; by 1966 when the IEEE Subcommittee on Pulse Techniques was formed, the previous edition of this standard was obsolete.

The greatest challenge the Subcommittee faced was the development of a standard which would satisfy the needs of a wide range of users whose measurement practices ranged from the casual and inexact to the most careful and exact. Since a standard which covers exact work can, by degradation or omission, also cover inexact work, the Subcommittee developed a standard which satisfies the needs of the user and manufacturer of sophisticated pulse apparatus. In doing this the Subcommittee found it necessary to define or describe in a rigorous manner a number of well-established terms and techniques. Nonetheless, careful study of this standard will show that the techniques and practices of the more casual user have been preserved.

The Subcommittee also made the following decisions relative to the content of this standard: (1) No frequency domain terms (e.g., bandwidth) would be used or defined. (2) No terms which link the time and frequency domains (e.g., pulse bandwidth) would be used or defined. (3) No acronyms or coined words would be used or defined.

The Subcommittee minimized the introduction of new concepts. At the first reading it may appear that there is a significant amount of new material; this is not the case. Section 2, Definitions, merely defines terms and techniques, some, perhaps, for the first time, more completely, or to a finer level of distinction. Section 3, Measurement of Pulse Characteristics, presents a model of the pulse measurement process. Sections 5 through 9 merely extend analysis of the single pulse waveform to encompass both simpler and more complex waveforms. Only in Section 4 is new material found as follows:
(1) Section 4.2, Waveform Epoch Determination. This material is not really new, but a new emphasis is put on the choice of data. (2) Sections 4.3.1, and 4.3.2 do present new techniques for the determination of base magnitude, top magnitude, and pulse amplitude.

The presentation of material in this standard, and within its sections, starts with the most general concepts and proceeds to the presentation of concepts which are more specific *in terms of concepts which have been presented previously.* This arrangement, while sacrificing alphabetical listing, yields a logical presentation of significant tutorial value.

Since its formation in 1966 the IEEE Subcommittee on Pulse Techniques has been broadly based. Collectively, its members represented or provided liaison with seven IEEE Societies or Groups (Circuits and Systems, Computer, Electron Devices, Engineering in Medicine and Biology, Instrumentation and Measurement, Magnetics, and Nuclear and Plasma Sciences), six technical associations (American Society for Testing and Materials, Electronic Industries Association, Instrument Society of America, National Conference of Standards Laboratories, Precision Measurement Association, and Scientific Apparatus Makers Association), and three Technical Committees of the International Electrotechnical Commission (Electron Tubes and Valves, Electronic Measuring Equipment, and Magnetic Materials and Components). Nine members of the Subcommittee were from six countries other than the U.S. (France, Germany, Hungary, Japan, the Netherlands and the United Kingdom).

Beginning in 1970 the liaison between the Subcommittee and Technical Committee 66, Electronic Measuring Equipment, of the International Electrotechnical Commission (IEC), became progressively closer and culminated in an informal mutual understanding that both groups would attempt to provide their parent organizations with pulse standards which were the same. This goal was achieved; IEC Publication 469-2, 1974, Pulse Techniques and Apparatus, Part 2: Pulse Measurement and Analysis, General Considerations, is technically (and, otherwise, substantially) identical to this standard.

The IEEE Subcommittee on Pulse Techniques, which prepared this standard, had the following members:

P.E. Stuckert*, *Chairman* (1971-1977)
J.C. Hubbs, *Chairman* (1966-1971)

D. Antonucci
J. F. Bogan
J. R. Brown, Jr.
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S. S. Shamis
D. B. Sharp*
F. A. Thomas
A. A. Toppeto
C. E. White
J. Worcester
H. A. Zimmerman

* Members of International Electrotechnical Commission Technical Committee 66: Electronic Measuring Equipment, Subcommittee 66A: Generators, Working Group I: Pulse Techniques and Apparatus.

This Standard was approved by the IEEE G-IM Technical Committee on High Frequency Instrumentation and Measurement which has the following members:

G. U. Sorger, *Chairman*
B. O. Weinschel, *Vice-Chairman*

S. F. Adams
G. L. Allerton
T. N. Anderson
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J. McKiernan
J. R. Reeder
U. L. Rohde
R. M. Showers
R. A. Soderman
P. E. Stuckert

Contents

An American National Standard

IEEE Standard on Pulse Measurement and Analysis by Objective Techniques

1. General

1.1 Scope. This standard provides definitions and descriptions of the techniques and procedures for time domain pulse measurements. The definitions and descriptions provided are independent of specific devices, apparatus, instruments, or computing devices which may be used in pulse measurements and are prerequisite to:

(1) Efficient communication of the results of pulse measurements

(2) Standards for pulse apparatus

(3) Standards for apparatus which employs pulse techniques.

1.2 Object. Within its scope, the object of this standard is the definition of terms and the description of techniques and procedures which are applicable:

(1) To the determination of the characteristics of practical and hypothetical pulses

(2) Regardless of accuracy or precision

(3) To a wide range of technologies and disciplines.

2. Definitions

For the definitions of general pulse terms used in this standard reference should be made to IEEE Std 194-1977, IEEE Standard Pulse Terms and Definitions. Throughout this standard, where required, specific sections of IEEE Standard 194-1977 are referenced.

2.1 Pulse Measurement Terms. The pulse measurement terms defined in this section are applicable to measurement in general and are not defined in order to draw a distinction between pulse measurement and measurement in general.

For the purposes of this standard, the following definitions shall apply.

2.1.1 ***Pulse Measurement.*** The assignment of a number and a unit of measurement to a characteristic, property, or attribute of a pulse wherein the number and unit assigned indicate the magnitude of the characteristic which is associated with the pulse. Typically, this assignment is accomplished by comparison of a transform of the pulse, its pulse waveform, with a scale or reference which is calibrated in the unit of measurement.

2.1.2 ***Method of Pulse Measurement.*** A method of making a pulse measurement comprises:

(1) The complete specification of the functional characteristics of the devices, apparatus, instruments, and auxiliary equipment to be used

(2) The essential adjustments required

(3) The procedures to be used in making essential adjustments

(4) The operations to be performed and their sequence

(5) The corrections that will ordinarily need to be made

(6) The procedures for making such corrections

(7) The conditions under which all operations are to be carried out.

2.1.3 ***Pulse Measurement Process.*** A realization of a *method of pulse measurement*[1] in terms of specific devices, apparatus, instruments, auxiliary equipment, conditions, operators, and observers.

2.1.4 ***State of Statistical Control.*** In a *pulse measurement process,* that state wherein a degree of consistency among repeated measurements of a characteristic, property, or attribute is attained.

2.1.5 ***Accuracy.*** The degree of agreement between the result of the application of a *pulse measurement process* and the true magnitude of the pulse characteristic, property, or attribute being measured.

2.1.6 ***Precision.*** The degree of mutual agreement between the results of independent measurements of a pulse characteristic, prop-

[1]Terms shown in italic type are defined previously in this standard.

erty, or attribute yielded by repeated application of a *pulse measurement process.*

2.1.7 ***Resolution.*** The smallest change in the pulse characteristic, property, or attribute being measured which can unambiguously be discerned or detected in a *pulse measurement process.*

2.2 Statistical Terms. [Under consideration pending location of the IEEE (or other) standard which defines statistical terms. Statistical terms to be defined are listed in the following outline.]

2.2.1 ***Population, Distribution, and Sample***
2.2.1.1 *Population*
2.2.1.2 *Distribution*
2.2.1.3 *Sample*
2.2.2 ***Measures of Central Tendency***
2.2.2.1 *Mean*
2.2.2.2 *Mode*
2.2.2.3 *Median*
2.2.3 ***Measures of Dispersion***
2.2.3.1 *Standard Deviation*
2.2.3.2 *Range*
2.2.3.3 *Tolerance*
2.2.4 ***Other Statistical Terms***
2.2.4.1 *Occurrence Density Distribution*
2.2.4.2 *Histogram*

2.3 Waveform Formats. Waveforms may exist, be recorded, or be stored in a variety of formats. Throughout this standard it is assumed that:

(1) Waveform formats are in terms of Cartesian coordinates, or some transform thereof

(2) Conversion from one waveform format to any other is possible

(3) Such waveform format conversions can be made with *precision, accuracy,* and *resolution* which is consistent with the accuracy desired in the *pulse measurement process.*

NOTE: Throughout the remainder of this standard the term *accuracy* will be used in place of the phrase *accuracy, precision,* and *resolution.*

2.3.1 ***Pictorial Format.*** A graph, plot, or display in which a waveform is presented for observation or analysis. Any of the waveform formats defined in the following subsections may be presented in the pictorial format.

2.3.2 ***Equational Format.*** One or more algebraic equations which specify a waveform wherein, typically, a first equation specifies the waveform from t_0 to t_1, a second equation specifies the waveform from t_1 to t_2, etc. The equational format is typically used to specify hypothetical, ideal, or reference waveforms.

2.3.3 ***Sampled Format.*** A waveform which is a series of *sample* magnitudes taken sequentially or nonsequentially as a function of time. It is assumed that nonsequential samples may be rearranged in time sequence to yield the following sampled formats.

2.3.3.1 *Periodically Sampled Real Time Format.* A finite sequence of magnitudes m_0, m_1, $m_2, \cdots$, m_n each of which represents the magnitude of the wave at times t_0, $t_0 + \Delta t$, $t_0 + 2\Delta t, \cdots$, $t_0 + n\Delta t$, respectively, wherein the data may exist in a pictorial format or as a list of numbers.

2.3.3.2 *Periodically Sampled Equivalent Time Format.* A format which is identical to the *periodically sampled real time format,* above, except that the time coordinate is equivalent to and convertible to real time. Typically, each datum point is derived from a different measurement on a different wave in a sequence of waves.

2.3.3.3 *Aperiodically Sampled Real Time Format.* A format which is identical to the *periodically sampled real time format,* above, except that the sampling in real time is not periodic and wherein the data exists as coordinate point pairs, t_1, m_1; t_2, m_2; $\cdots$; t_n, m_n.

2.3.3.4 *Aperiodically Sampled Equivalent Time Format.* A format which is identical to the *aperiodically sampled real time format,* above, except that the time coordinate is equivalent to and convertible to real time. Typically, each datum point is derived from a different measurement on a different wave in a sequence of waves.

2.4 Waveform Epoch Expansion and Contraction

2.4.1 ***Waveform Epoch Expansion.*** A technique for the determination of the characteristics of a transition waveform (or pulse waveform) wherein the transition waveform epoch (or pulse waveform epoch) is expanded in time to a pulse waveform epoch (or waveform epoch) for the determination of magnitude or time reference lines. The reference lines determined by analysis of the pulse waveform (or waveform) are transferred to the transition waveform (or pulse waveform) for the determination of characteristics. In any waveform epoch expansion procedure two or more sets of reference lines may exist, and the set of reference lines being used in any *pulse measurement process* shall be specified. (See Fig 1.)

2.4.2 *Waveform Epoch Contraction.* A technique for the determination of the characteristics of individual pulse waveforms (or pulse waveform features) wherein the waveform epoch (or pulse waveform epoch) is contracted in time to a pulse waveform epoch (or transition waveform epoch) for the determination of time or magnitude characteristics. In any waveform epoch contraction procedure two or more sets of time or magnitude reference lines may exist, and the set of reference lines being used in any *pulse measurement process* shall be specified. (See Fig 1.)

2.5 Reference Pulse Waveforms. A reference pulse waveform (see IEEE Std 194-1977, Sections 2.4.1.3 and 2.8.1) may be specified by any of the *waveform formats* defined in Section 2.3, above. The characteristics of the devices, apparatus, techniques, or algorithms used in producing or deriving a reference pulse waveform shall be specified.

2.5.1 *Defined Reference Pulse Waveform.* A *reference pulse waveform* which is defined without reference to any practical or derived pulse waveform. Typically, a defined reference pulse waveform is an ideal pulse waveform.

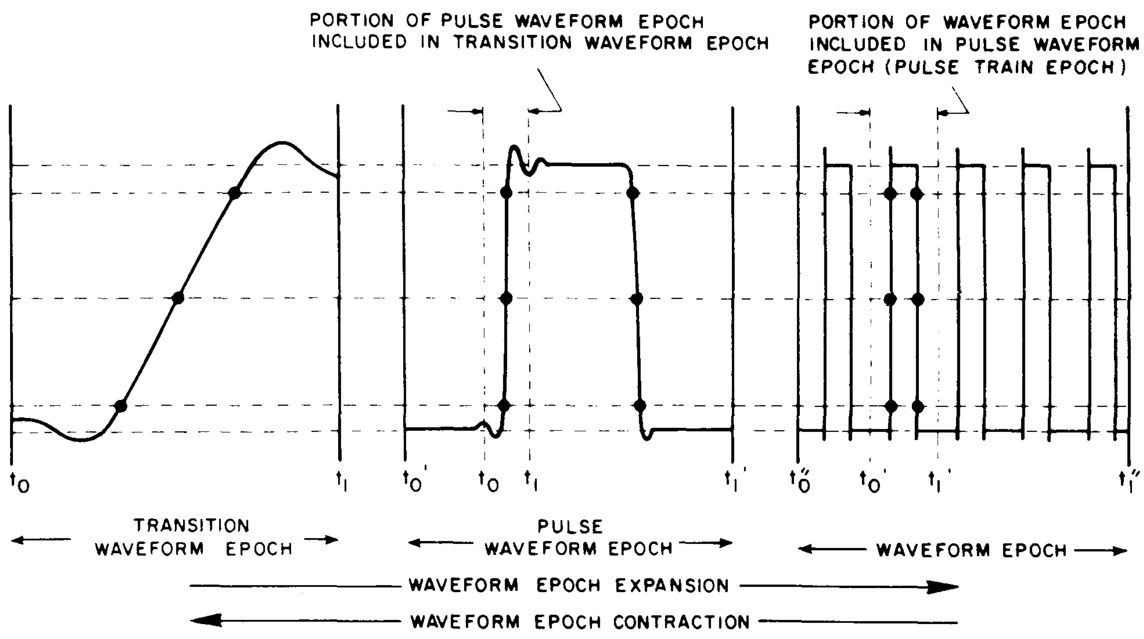
2.5.2 *Derived Reference Pulse Waveform.* A *reference pulse waveform* which is derived by a specified procedure or algorithm from the pulse waveform which is being analyzed in a *pulse measurement process.* (See Fig 2 for an example of a derived reference pulse waveform and its algorithm.)

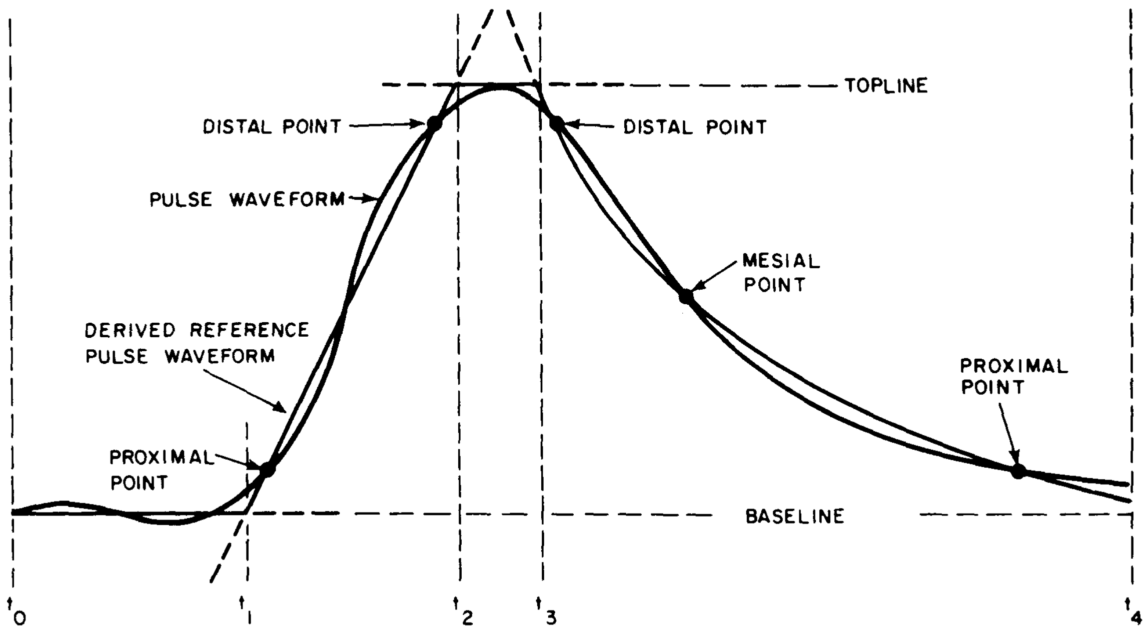
2.5.3 *Practical Reference Pulse Waveform.* A *reference pulse waveform* which is derived from a pulse which is produced by a device or apparatus.

3. Measurement of Pulse Characteristics

3.1 The Distinction Between Waves and Waveforms. The distinction between waves, pulses, and transitions and their respective waveforms is clearly drawn; the former are modifications of the physical state of a medium, or phenomena, while the latter are manifestations, representations, or visualizations of these phenomena (see IEEE Std 194-1977, Sections 2.2 and 2.3.1).

Fig 1
Waveform Epoch Expansion and Contraction





SEGMENT	DESCRIPTION
$t_0 - t_1$	Equal to magnitude and slope of baseline
$t_1 - t_2$	Straight line through first transition proximal and distal points
$t_2 - t_3$	Equal to magnitude and slope of topline
$t_3 - t_4$	Exponential curve through last transition proximal, mesial, and distal points

Fig 2
Derived Reference Pulse Waveform

NOTE: Throughout the remainder of this standard the terms pulse and pulse waveform are used in the following inclusive sense: the terms pulse and pulse waveform include the terms transition and transistion waveform, respectively, and insofar as is applicable, the terms pulse and pulse waveform include the terms wave and waveform, respectively.

3.2 Description of the Pulse Measurement Process. The object of any *pulse measurement process* is the determination to some *accuracy,* either expressed or implied, of the magnitude of a characteristic, property, or attribute of a pulse. Fig 3 shows the constituent steps of any *pulse measurement process* where, as indicated, the process involves two distinct sequential subprocesses: pulse-to-pulse waveform conversion and pulse waveform analysis. Thus, the *pulse measurement process* involves:

(1) The conversion of a pulse into its transform, its pulse waveform

(2) Analysis of the pulse waveform to determine the magnitude of a pulse waveform characteristic

(3) The assertion or assumption that the magnitude of the pulse waveform characteristic thus determined is, to some *accuracy,* identical to the magnitude of the pulse characteristic.

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

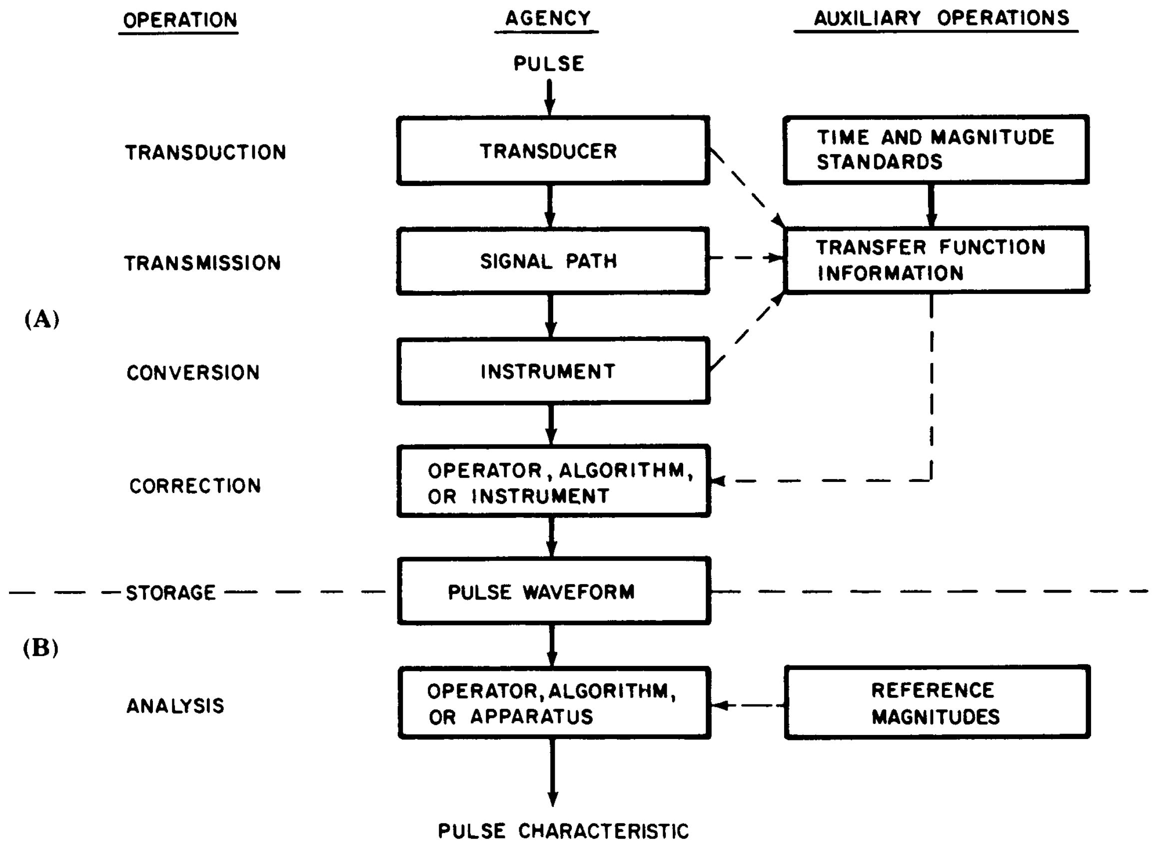


Fig 3
Pulse Measurement Process
A — Pulse-to-Pulse Waveform Conversion
B — Pulse Waveform Analysis

provide pulse-to-pulse waveform conversion renders the discussion of specific implementations beyond the scope of this standard. Such discussion is deferred to other standards, documents, or specifications which describe or define the characteristics or methods of specific devices, apparatus, instruments, or techniques. A state of statistical control must be achieved before a *pulse measurement process* can be considered to be a realization of a *method of pulse measurement.*

3.3 Pulse-to-Pulse Waveform Conversion. Fig 3A shows the five basic operations — transduction, transmission, conversion, correction, and storage — which, in some sense, are always present in pulse-to-pulse waveform conversion. The order in which these basic operations occur is not necessarily that shown in the figure and, frequently, an operation occurs more than once.

Three of the basic operations, that is, transduction, transmission, and conversion, involve apparatus or devices whose transfer functions must be known to an *accuracy* which is consistent with the overall *accuracy* desired in the *pulse measurement process.* The determination of transfer functions is indicated in Fig 3A by the dashed lines leading to auxiliary operations. In these auxiliary operations, which may be other *pulse measurement processes,* the transfer functions of the apparatus are:

(1) Adjusted to predetermined values, that is, the apparatus is calibrated or

(2) Determined and retained for subsequent

use in the correction operation.

Fig 3A also shows that the determination or adjustment of transfer functions entails comparison, either directly or indirectly, with basic or derived time and magnitude standards.

The following sections describe each of the five operations which are present in pulse-to-pulse waveform conversion.

3.3.1 ***Transduction.*** Pulses propagate in numerous modes in gases, liquids, solids, in vacuum, and in networks made up of such media. In transduction a device or apparatus abstracts energy from the medium in which the pulse propagates and converts the energy to a form suitable for transmission.

3.3.2 ***Transmission.*** Transmission may occur over signal paths which utilize radiative, electrical, hydraulic, pneumatic, or mechanical phenomena or analog to digital or digital to analog conversion techniques.

3.3.3 ***Conversion.*** Typically, the conversion operation involves an instrument which combines its input signal with a real or equivalent time base. Such an instrument may provide a display of the combination of the input signal and the time base, and such displays frequently function as the storage operation (see Section 3.3.5). Display is not necessarily an attribute of the conversion operation.

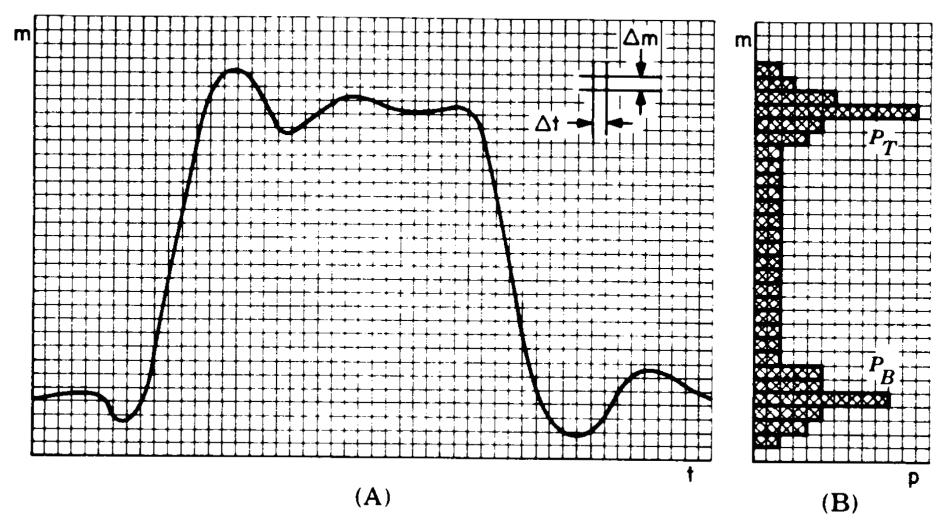
3.3.4 ***Correction.*** The correction operation combines the results of the conversion operation with the transfer function information to yield a pulse waveform which is a more accurate transform of the pulse. Correction may be effected by a mental process by an operator, a computational process, or a compensating device or apparatus. Correction must be performed to an *accuracy* which is consistent with the overall *accuracy* desired in the *pulse measurement process.*

3.3.5 ***Storage.*** Storage is a transitional operation between pulse-to-pulse waveform conversion and pulse waveform analysis. Storage may be effected in numerous ways, and display is not required, but the stored data must be available or retrievable for pulse waveform analysis. Typically, storage is effected in one of the *waveform formats* defined in Section 2.3.

4. Pulse Waveform Analysis

4.1 Generality of Pulse Waveform Analysis. Pulse waveform analysis has broad utility since, when it is combined with *waveform epoch expansion* and *contraction* or applied to waveforms which are produced by operations on pulse waveforms (see IEEE Std 194-1977, Section 5.5.1), its principles and techniques apply to:

Fig 4
Graphical Determination of Occurrence Density
A — Pulse Waveform With Superimposed Grid
B — Probability Density Histogram



(1) Transition waveform analysis

(2) Analysis of complex waveforms

(3) Analysis of the constituent pulse waveforms of a pulse train or pulse burst

(4) Analysis of the top and base envelopes of a pulse burst

and are prerequisite to:

(1) Analysis of the time relationships between different waveforms

(2) Analysis of distortion, jitter, and fluctuation.

4.2 Waveform Epoch Determination

4.2.1 *Selection of Pulse Waveform Epoch.* A pulse waveform epoch (see IEEE Std 194-1977, Section 2.3.2) is the span of time for which waveform data are known or knowable, and all analysis is based on the data within the epoch. These data may be augmented by reference lines which are determined by *waveform epoch expansion* or *contraction.* In any *pulse measurement process* sufficient data must be present to yield base and top magnitudes (see IEEE Std 194-1977, Section 3.2.1 and 3.2.2) which are consistent with the *accuracy* desired in the *pulse measurement process.*

4.2.2 *Exclusion of Data From Analysis.* Data in a pulse waveform epoch may be excluded from the analysis under certain conditions, for example:

(1) Base magnitude may be determined solely from data which precedes the first transition

(2) A pulse waveform may include features or events which are nonpertinent in the circumstances of or to the application of the pulse. Nonpertinent data may be excluded from analysis, however, such exclusions may only be made on the basis of demonstrable information or knowledge.

When data within a pulse waveform epoch is excluded from analysis the following shall be specified:

(1) The extent, in time or magnitude, of the excluded data

(2) The demonstrable information or knowledge which justifies the exclusion

(3) Whether the excluded data is ignored (that is, the waveform which is analyzed is discontinuous) or replaced (that is, the excluded data is replaced with other assumed or derived data).

4.3 Analysis of the Single Pulse Waveform. Pulse waveform analysis may be effected by:

(1) A mental process by an operator

(2) A computational process

(3) An apparatus or instrument.

In all cases the pulse waveform is operated upon by the analyzing algorithm(s) and the same principles apply regardless of the *pulse waveform format* or the analyzing agency. Throughout this section it is assumed that the analysis is performed by a computing device since this method:

(1) Is the most general

(2) Is potentially the most accurate

(3) Fully illustrates the operations which an operator or apparatus must, in some sense and to some *accuracy,* perform.

The analysis of the single pulse waveform requires the sequential determination of the following:

(1) Base magnitude and top magnitude

(2) Pulse amplitude

(3) Proximal, mesial, and distal lines and points

(4) Magnitudes of all other pulse waveform characteristics as computed differences between line or point pairs.

Typically, each of the preceding determinations is a prerequisite to the succeeding determination. Thus, algorithms for the determination of base magnitude, top magnitude, and pulse amplitude only are described in the following since the determination of all other pulse waveform characteristics proceeds directly from these determinations (See IEEE Std 194-1977, Section 3).

4.3.1 ***Base and Top Magnitude Algorithms.*** In the following sections algorithms for determining base magnitude, and top magnitude are described together. There is, however, no requirement that the same algorithm be used for both determinations.

4.3.1.1 *Mean of Density Distribution.* This algorithm is based on determinations of the *means* of the *occurrence density distribution* of a pulse waveform. A graphical description follows:

(1) Assume that a pulse waveform, such as that shown in Fig 4A, has a superimposed rectangular grid in which each elementary rectangle has dimensions Δt and Δm.

(2) Develop the occurrence density *histogram* as follows:

(a) For each horizontal element, of width Δm, count the number of elementary rectangles through which the pulse waveform passes

(b) At the magnitude corresponding to the location of the horizontal element, draw a *histogram* element whose length is proportional to the count. This procedure yields the truncated bimodal *histogram* of Fig 4B in which P_B, the base *histogram*, and P_T, the top *histogram*, are identified.

(3) Consider the *histograms* P_B and P_T separately and calculate the magnitudes of the *means of* P_B and P_T and take the magnitudes of these *means* as the base magnitude and top magnitude, respectively.

This algorithm is best suited to the analysis of pulse waveforms with bases and tops of significant relative duration when the highest *accuracy* in the analysis is desired.

A graphical solution yields crude results, but as Δt and Δm become smaller, numerical calculation of the *means* of P_B and P_T become more refined measures of the base and top magnitudes.

4.3.1.2 *Mode of Density Distribution.* This algorithm is based on determinations of the *modes* of the *occurrence density distribution* of a pulse waveform and is identical to the algorithm described in Section 4.3.1.1 except for step (3) which is:

(3) Consider the *histograms* P_B and P_T separately and determine the magnitudes of the *modes* of P_B and P_T and take the magnitudes of these *modes* as the base magnitude and top magnitude, respectively.

This algorithm is best suited to the analysis of pulse waveforms with bases and tops of significant relative duration when results which are compatible with visual observation and mental analysis by an operator are desired.

4.3.1.3 *Peak Magnitude.* Determine the positive peak and negative peak magnitudes of the pulse waveform.

(1) Take the positive peak magnitude as the top (base) magnitude of a positive (negative) pulse waveform

(2) Take the negative peak magnitude as the base (top) magnitude of a positive (negative) pulse waveform.

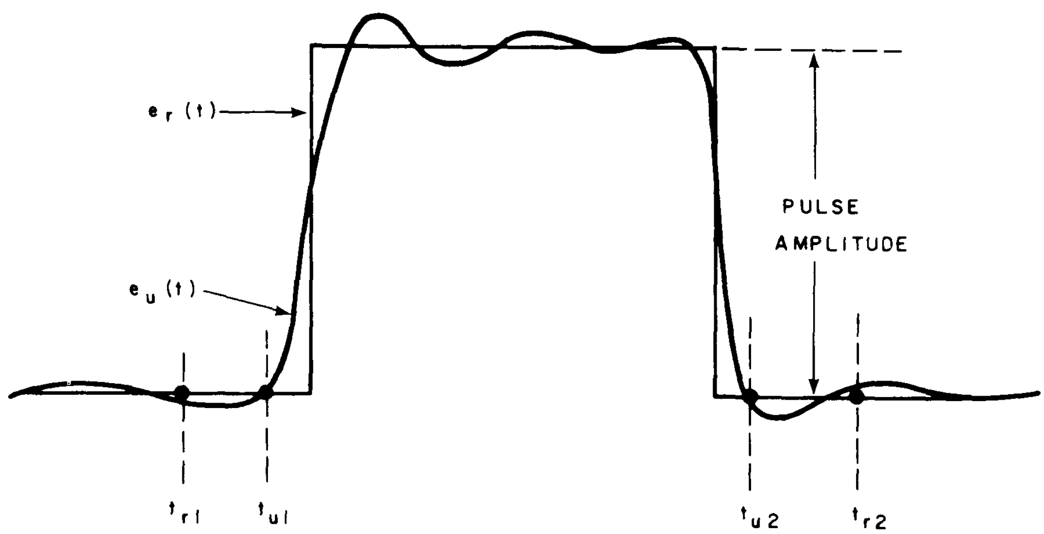
This algorithm is best suited to the analysis of pulse waveforms with bases (tops) of negligible or relatively short duration.

4.3.1.4 *First (Last) Base Point.* Determine the magnitude of the first (last) base point (see IEEE Std 194-1977, Section 3.3.4.2). Take the magnitude of the first (last) base point as the base magnitude.

4.3.2 ***Pulse Amplitude Algorithms.***

4.3.2.1 Pulse amplitude is the algebraic difference between the top magnitude and the

Fig 5
Determination of Pulse Amplitude by Integral Technique



base magnitude (see IEEE Std 194-1977, 3.2.3). Where the absolute magnitude of the base (or top) magnitude is either immaterial in a pulse waveform analysis, or known from other measurements, the determination of pulse amplitude is sufficient.

Fig 5 illustrates the determination of pulse amplitude by the integral technique wherein the pulse waveform whose pulse amplitude is unknown $e_u(t)$ and a *practical reference pulse waveform* $e_r(t)$ are alternately delivered to an instrument:

(1) Which has an input impedance of R Ω

(2) Which can perform the integrations shown in Eqs 1 and 2

(3) Which indicates when Eqs 1 and 2 are satisfied.

$$\int_{t_{u1}}^{t_{u2}} e_u(t)\,dt = \int_{t_{r1}}^{t_{r2}} e_r(t)\,dt \qquad \text{(Eq 1)}$$

$$\frac{1}{R}\int_{t_{u1}}^{t_{u2}} [e_u(t)]^2\,dt = \frac{1}{R}\int_{t_{r1}}^{t_{r2}} [e_r(t)]^2\,dt \qquad \text{(Eq 2)}$$

When Eqs 1 and 2 are satisfied, the pulse amplitude of the unknown pulse waveform, $e_u(t)$, is taken as equal to the pulse amplitude of the *practical reference pulse waveform*, $e_r(t)$. It is not necessary that the integrals of $e_u(t)$ and $e_r(t)$ be evaluated between identical limits. In fact, as is indicated for $e_u(t)$ in Fig. 5, it is preferable that the extent of the integration(s) be adjusted so that distortions which precede and follow the pulse waveform(s) do not contribute to the integral(s).

This algorithm is best suited to analysis in which an unknown pulse waveform and a *practical reference pulse waveform* with very nearly identical pulse shapes are compared.

4.3.3 *Determination of Other Pulse Characteristics.* When the (1) base magnitude and top magnitude or (2) base magnitude and pulse amplitude of a pulse waveform have been determined, the determination of all other pulse characteristics follows directly from existing definitions of:

(1) Proximal, mesial, and distal lines and points (see IEEE Std 194-1977, Section 3.2).

(2) The magnitudes of all other pulse waveform characteristics as computed differences between line or point pairs (see IEEE Std 194-1977, Section 3.3).

5. Analysis of Transition Waveforms

Transition waveform analysis is a special case of pulse waveform analysis in which the analysis centers on a specified transition waveform of a pulse waveform. *Waveform epoch expansion* may be used to establish the time and magnitude reference lines required in transition waveform analysis.

6. Analysis of Complex Waveforms

Typically, the analysis of complex waveforms involves:

(1) Decomposition of the complex waveform into more elementary constituent pulse waveforms or

(2) Conversion of a multiplicity of constituent elements into pulse waveforms.

In any analysis of complex waveforms the algorithms or procedures used in decomposition or conversion shall be specified.

6.1 Analysis of Combinations of Pulses and Transitions. Double pulse, bipolar pulse, or staircase waveforms (see IEEE Std 194-1977, Section 5.1) may be analyzed by decomposing the waveform into constituent pulse and transition waveforms. Typically, the decomposition is effected by subdividing the waveform at specified time referenced points.

6.2 Analysis of Waveforms Produced by Magnitude Superposition. Offset or composite waveforms (see IEEE Std 194-1977, Section 5.2) may be analyzed by decomposing the waveform into constituent constant, pulse, and transition waveforms. Typically, the decomposition is effected by a process which is the inverse of magnitude superposition.

6.3 Analysis of Waveforms Produced by Continuous Time Superposition of Simpler Waveforms. The constituent pulse waveforms of a pulse train (see IEEE Std 194-1977, Section 5.3.1) may be analyzed by decomposition. Typically, the decomposition is effected by subdividing the pulse train into pulse train epochs (see IEEE Std 194-1977, Section 5.3.2.8), each of which includes a single constituent pulse waveform.

6.4 Analysis of Waveforms Produced by Noncontinuous Time Superposition of Simpler Waveforms. The constituent pulse waveforms of a pulse burst (see IEEE Std 194-1977, Section 5.4.1) may be analyzed in a manner identical to that described in Section 6.3.

The overall characteristics of a pulse burst may be analyzed by conversion of the pulse burst into its pulse burst top envelope and pulse burst base envelope (see IEEE Std 194-1977, Sections 5.5.1.2 and 5.5.1.3).

These envelopes are then analyzed as single pulse waveforms.

7. Analysis of Time Relationships Between Different Waveforms

The time relationships between different waveforms may be analyzed by:

(1) Applying the methods described in Sections 4, 5, and 6, in the analysis of the different waveforms and

(2) Determining the time relationships between different waveforms (see IEEE Std 194-1977, Section 6) as computed intervals or durations.

8. Analysis of Pulse Waveform Distortion

Pulse waveform distortion and pulse waveform feature distortion entail the determination of the differences between a pulse waveform and a *reference pulse waveform* (see IEEE Std 194-1977, Section 7.1). In any distortion determination the type of *reference pulse waveform,* which may be any of the types defined in Section 2.5 shall be specified.

When the *reference pulse waveform* is a *practical reference pulse waveform* or a *defined reference pulse waveform,* it must be properly located, in time and magnitude, relative to the pulse waveform being analyzed. When the *reference pulse waveform* is a *derived reference pulse waveform,* its location relative to the waveform being analyzed is fixed by definition and shall not be altered.

9. Analysis of Jitter and Fluctuation

The measurement of jitter only or fluctuation only in the substantial absence of the other is, typically, a relatively straightforward process. When, however, jitter and fluctuation are both present in significant amounts, these components must be separated. Typically, separation is accomplished by first measuring fluctuation at points of zero waveform slope and subsequently applying the known fluctuation as a correction in the determination of jitter.

9.1 Analysis of Jitter. The analysis of jitter involves:

(1) The repeated determination of a time characteristic of the constituent pulse waveforms in a pulse train and

(2) The determination of the instability of the measured time characteristic with respect to a reference time, interval, or duration (see IEEE Std 194-1977, Section 7.3.1).

Jitter analysis, thus, involves the application of the methods of measurement described in Sections 4, 5, 6, and 7, as required, to a multiplicity of the constituent pulse waveforms in a pulse train.

9.2 Analysis of Fluctuation. The analysis of fluctuation involves:

(1) The repeated determination of a magnitude characteristic of the constituent pulse waveforms in a pulse train and

(2) The determination of the instability of the measured magnitude characteristic with respect to a reference magnitude characteristic (see IEEE Std 194-1977, Section 7.3.2).

Fluctuation analysis, thus, involves the application of the methods of measurement described in Sections 4, 5, 6, and 7, as required, to a multiplicity of the constituent pulse waveforms in a pulse train.