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European Standard (Telecommunications series)

**Transmission and Multiplexing (TM);
Generic requirements for synchronization networks;
Part 1-1: Definitions and terminology
for synchronization networks**

Reference

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Keywords

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ETSI

Postal address

F-06921 Sophia Antipolis Cedex - FRANCE

Office address

650 Route des Lucioles - Sophia Antipolis
Valbonne - FRANCE
Tel.: +33 4 92 94 42 00 Fax: +33 4 93 65 47 16
Siret N° 348 623 562 00017 - NAF 742 C
Association à but non lucratif enregistrée à la
Sous-Préfecture de Grasse (06) N° 7803/88

Internet

secretariat@etsi.fr
http://www.etsi.fr
http://www.etsi.org

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Foreword

This European Standard (Telecommunications series) has been produced by the Transmission and Multiplexing (TM) Technical Committee.

The present document has been produced to provide requirements for synchronization networks that are compatible with the performance requirements of digital networks. It is one of a family of documents covering various aspects of synchronization networks:

Part 1-1: **"Definitions and terminology for synchronization networks";**

Part 2-1: "Synchronization network architecture";

Part 3-1: "The control of jitter and wander within synchronization networks";

Part 4-1: "Timing characteristics of slave clocks suitable for synchronization supply to Synchronous Digital Hierarchy (SDH) and Plesiochronous Digital Hierarchy (PDH) equipment";

Part 4-2: "Timing characteristics of slave clocks suitable for synchronization supply to Synchronous Digital Hierarchy (SDH) and Plesiochronous Digital Hierarchy (PDH) equipment Implementation Conformance (ICS) Statement";

Part 5-1: "Timing characteristics of slave clocks suitable for operation in Synchronous Digital Hierarchy (SDH) equipment";

Part 6-1: "Timing characteristics of primary reference clocks";

Part 6-2: "Timing characteristics of primary reference clocks Implementation Conformance (ICS) Statement";

Part 7-1: "Timing characteristics of slave clocks suitable for synchronization supply to equipment in local node applications".

Parts 1-1, 2-1, 3-1 and 5-1 have previously been published as ETS 300 462 Parts 1, 2, 3 and 5, respectively.

Additionally, parts 4-1 and 6-1 completed the Voting phase of the Two Step Approval procedure as ETS 300 462 Parts 4 and 6, respectively.

It was decided to prepare ICS proformas for several of the parts and this necessitated a re-numbering of the individual document parts. It was also decided to create a new part 7-1.

This in turn led to a need to re-publish new versions of all six parts of the original ETS. At the same time, the opportunity was taken to convert the document type to EN.

This has involved no technical change to any of the documents. However part 5-1 has been modified, due to editorial errors which appeared in ETS 300 462-5.

Transposition dates	
Date of adoption:	4 April 1997
Date of latest announcement of this ETS (doa):	31 July 1997
Date of latest publication of new National Standard or endorsement of this ETS (dop/e):	31 January 1998
Date of withdrawal of any conflicting National Standard (dow):	31 January 1998

NOTE: The above transposition table is the original table from ETS 300 462-1 (April 1997, see History).

1 Scope

The present document specifies the definitions and abbreviations, used in the other parts of EN 300 462.

2 References

The following documents contain provisions which, through reference in this text, constitute provisions of the present document.

- References are either specific (identified by date of publication, edition number, version number, etc.) or non-specific.
- For a specific reference, subsequent revisions do not apply.
- For a non-specific reference, subsequent revisions do apply.
- A non-specific reference to an ETS shall also be taken to refer to later versions published as an EN with the same number.

[1] ITU-R Recommendation 686 (1990): "Standard frequencies and time signals -Glossary".

[2] ETS 300 147 (1996): "Transmission and Multiplexing (TM); Synchronous Digital Hierarchy (SDH) Multiplexing Structure".

[3] EN 300 462-4-1: "Transmission and Multiplexing (TM); Generic requirements for synchronization networks; Part 4-1: Timing characteristics of slave clocks suitable for synchronization supply to Synchronous Digital Hierarchy (SDH) and Plesiochronous Digital Hierarchy (PDH) equipment".

[4] EN 300 462-5-1: "Transmission and Multiplexing (TM); Generic requirements for synchronization networks; Part 5-1: Timing characteristics of slave clocks suitable for operation in Synchronous Digital Hierarchy (SDH) equipment".

[5] EN 300 462-6-1: "Transmission and Multiplexing (TM); Generic requirements for synchronization networks; Part 6-1: Timing characteristics of primary reference clocks".

[6] ITU-T Recommendation G.701 (1993): "Vocabulary of digital transmission and multiplexing, and pulse code modulation (PCM) terms".

[7] ITU-T Recommendation G.704 (1995): "Synchronous frame structures used at 1 544, 6 312, 2 048, 8 488 and 44 736 kbit/s hierarchical levels".

[8] ITU-T Recommendation G.832 (1995): "Transport of SDH elements on PDH networks: Frame and multiplexing structures".

3 Definitions and abbreviations

3.1 Definitions

For the purposes of the present document, the following definitions apply:

3.1.1 General definitions

bilateral: A synchronization link where the corrective action to maintain locking is active at both ends of the link.

jitter: Short term variations of the significant instants of a digital signal from their reference positions in time.

network synchronization: A generic concept that depicts the way of distributing a common time and/or frequency to all elements in a network.

single ended synchronization: A method of synchronizing a specified synchronization node with respect to another synchronization node in which synchronization information at the specified node is derived from the phase difference between the local clock and the incoming digital signal from the other node.

slip: The repetition or deletion of a block of bits in a synchronous or plesiochronous bit stream due to a discrepancy in the read and write rates at a buffer.

synchronization chain: An active interconnection of synchronization nodes and links.

synchronization reference chain: A specific synchronization chain defined in the present multi-part document to form the basis for simulations of jitter and wander in the synchronization network.

synchronization status message: A coding of the reference level of the timing source as specified in ETS 300 147 [2] for STM-N, ITU-T Recommendation G.704 [7] for 2 048 kbit/s, ITU-T Recommendation G.832 [8] for synchronous 34 Mbit/s and 140 Mbit/s.

time: Is used to specify an instant (time of the day) or as a measure of time interval.

> NOTE 1: The words time or timing, when used to describe synchronization networks, usually refer to the frequency signals used for synchronization or measurement.

time scale: A system of unambiguous ordering of events.

> NOTE 2: This could be a succession of equal time intervals, with accurate references of the limits of these time intervals, which follow each other without any interruption since a well defined origin. A time scale allows to date any event. For example, calendars are time scales. A frequency signal is not a time scale (every period is not marked and dated). For this reason "Universal Time Coordinated (UTC) frequency" should be used instead of "UTC".

unilateral: A synchronization link where the corrective action to maintain locking is only active at one end of the link.

Universal Time Coordinated (UTC): The time scale, maintained by the Bureau International des Poids et Mesures (BIPM) and the International Earth Rotation Service (IERS), which forms the basis of a coordinated dissemination of standard frequencies and time signal.

> NOTE 3: The reference frequency for network synchronization is the frequency which generates the UTC time scale. It is therefore preferable to use the words "UTC frequency" instead of "UTC".

wander: The long term variations of the significant instances of a digital signal from their ideal positions in time (where long term implies that these variations are of frequencies less than 10 Hz).

> NOTE 4: For the purposes of the present multi-part document, this definition of wander does not include integrated frequency departure.

3.1.2 Definitions related to clock equipments

clock: A device which provides a reference timing signal.

frequency standard: A generator, the output of which is used as a measurement reference timing signal.

local node: A synchronous network node which interfaces directly with customer equipment.

master clock: A clock providing a reference timing signal to other clocks, behaving as slave clocks.

node clock: Clock distributing synchronization reference timing signals within a node.

Primary Reference Clock (PRC): A reference clock that provides a reference timing signal compliant with EN 300 462-6-1 [5], in order to synchronize all or a large part of a network.

slave clock: A clock which is locked to a reference timing signal.

NOTE 1: When a slave clock loses all its reference timing signals and goes holdover, it can be considered as being a master clock under these conditions.

NOTE 2: In locked mode, the slave clock is synchronized to a reference timing signal. The output frequency of the clock is the same as the frequency of the reference timing signal over the long term, and the phase difference between the input and the output is bounded.

Stand Alone Synchronization Equipment (SASE): The stand alone implementation of the logical SSU function, which incorporates its own management function.

Synchronization Supply Unit (SSU): A logical function for reference timing signal selection, processing and distribution, having the frequency characteristics given in EN 300 462-4-1 [3].

transit node: A synchronous network node which interfaces with other nodes and does not directly interface with customer equipment.

3.1.3 Definitions related to synchronization networks

asynchronous mode: A mode where clocks are intended to operate in free running mode.

NOTE: This definition applies to clocks. However a more general definition applying to data network is in ITU-T Recommendation G.701 [6].

master slave mode: A mode where a designated master clock provides reference timing signals which are disseminated to all other clocks which are slaved to the master clock.

mutually synchronized mode: A mode where all clocks exert a degree of control of each other.

plesiochronous mode: A mode where the essential characteristic of time scales or signals such that their corresponding significant instants occur at nominally the same rate, any variation in rate being constrained within specified limits.

pseudo-synchronous mode: A mode where all clocks have a long term frequency accuracy compliant with a primary reference clock as specified in EN 300 462-6-1 [5] under normal operating conditions. Not all clocks in the network will have timing traceable to the same PRC.

synchronization link: A link between two synchronization nodes over which a reference timing signal is transmitted.

synchronization network: A network to provide reference timing signals. In general, the structure of a synchronization network comprises synchronization nodes connected by synchronization links.

synchronization trail: The logical representation of one or several synchronization links.

synchronous network: Where all clocks have the same long term accuracy under normal operating conditions.

3.1.4 Definitions related to clock modes of operation (applicable to slave clocks)

free running mode: An operating condition of a clock, the output signal of which is strongly influenced by the oscillating element and not controlled by servo phase-locking techniques. In this mode, the clock has never had a network reference input, or the clock has lost external reference and has no access to stored data, that could be acquired from a previously connected external reference. Free-run begins when the clock output no longer reflects the influence of a connected external reference, or transition from it. Free run terminates when the clock output has achieved lock to an external reference.

holdover mode: An operating condition of a clock which has lost its controlling input and is using stored data, acquired while in locked operation, to control its output. The stored data are used to control phase and frequency variations, allowing the locked condition to be reproduced within specifications. Holdover begins when the clock output no longer reflects the influence of a connected external reference, or transition from it. Holdover terminates when the output of the clock reverts to locked mode condition.

locked mode: An operating condition of a clock in which the output signal is controlled by an external input reference. It is the expected mode of operation of a slave clock and the state in which each clock within a chain of clocks has the same long term average frequency.

3.1.5 Definitions related to clock characterization

ageing: The systematic change in frequency of an oscillator with time.

NOTE 1: It is the frequency drift when factors external to the oscillator (environment, power supply, temperature, etc.) are kept constant. An ageing value should always be specified together with the corresponding duration.

fractional frequency deviation: The difference between the actual frequency of a signal and a specified nominal frequency, divided by the nominal frequency. Mathematically, the fractional frequency deviation y(t) can be expressed as:

$$y(t) = \frac{v(t) - v_{nom}}{v_{nom}}$$

frequency accuracy: The maximum magnitude of the fractional frequency deviation for a specified time period.

NOTE 2: The frequency accuracy includes the initial frequency offset and any ageing and environmental effect.

frequency drift: The systematic change in frequency of an oscillator caused by ageing and external effects (radiation, pressure, temperature, humidity, power supply, load, etc.).

NOTE 3: The external factors should always be clearly indicated.

frequency stability: The spontaneous and/or environmentally caused frequency change within a given time interval.

NOTE 4: It is generally distinguished between systematic effects such as frequency drift effects (caused by radiations, pressure, temperature, humidity, power supply, charge, ageing etc.) and stochastic frequency fluctuations which are typically characterized in time domain (special variances have been developed for the characterization of these fluctuations: Allan variance, modified Allan variance, Allan variance in time) and/or frequency domain (one sided spectral densities).

Maximum Relative Time Interval Error (MRTIE): The maximum peak-to-peak delay variation of an output timing signal with respect to a given input timing signal within an observation time ($\tau = n\tau_0$) for all observation times of that length within the measurement period (T).

Maximum Time Interval Error (MTIE): The maximum peak-to-peak delay variation of a given timing signal with respect to an ideal timing signal within an observation time ($\tau = n\tau_0$) for all observation times of that length within the measurement period (T). It is estimated using the following formula:

$$\mathrm{MTIE}\left(n\tau_0\right) = \max_{1 \le k \le N-n}\left(\max_{k \le i \le k+n}(xi) - \min_{k \le i \le k+n}(xi)\right), \qquad n = 1, 2, \ldots, (N-1)$$

measurement reference timing signal: A timing signal of specified performance used as a time base for clock characterization measurements. The basic assumption is that its performance must be significantly better than the clock under test with respect to the parameter being tested, in order to prevent the test results being compromised. The performance parameters of the frequency standard must be stated with all test results.

phase transient: Perturbations in phase of limited duration.

pull in range: The largest offset between a slave clock's reference frequency and a specified nominal frequency, within which the slave clock will achieve locked mode.

pull out range: The offset between a slave clock's reference and a specified nominal frequency, within which the slave clock stays in the locked mode and outside of which the slave clock cannot maintain locked mode, irrespective of the rate of the frequency change.

reference timing signal: A timing signal of specified performance that can be used as a timing source for a slave clock.

Time Deviation (TDEV or $\sigma_x(\tau)$): A measure of the expected time variation of a signal as a function of integration time. TDEV can also provide information about the spectral content of the phase (or time) noise of a signal. TDEV is in units of time. Based on the sequence of time error samples, TDEV is defined by the following calculation:

$$\mathrm{TDEV}(\tau) = \sqrt{\frac{1}{(6n^2(N-3n+1))}\sum_{j=1}^{N-3n+1}\left(\sum_{i=j}^{n+j-1}(x_{i+2n} - 2x_{i+n} + x_i)\right)^2}$$

where: x_j are samples of time errors data;
N is the total number of samples;
τ_o is the time error sampling interval;
τ is the integration time, the independent variable of the Time Deviation (TDEV);
n is the number of sampling intervals, with n = 1,2,...,integer part (N/3).

Thus the integration time $\tau = n\tau_o$.
Annex B gives technical information on TDEV parameter.

time error function: The difference between the time of that clock and the frequency standard one. Mathematically, the time error function x(t) between a clock generating time T(t) and a reference clock generating time $T_{ref}(t)$ is defined as:

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

At a purely abstract level of definition, the frequency standard can be thought of as ideal (i.e. $T_{ref}(t) = t$ can be assumed); since ideal time is not available for measurement purposes, ideal time error is of no practical interest.

Time error is the basic function whereby many different stability parameters (such as Maximum Time Interval Error (MTIE), root mean square Time Interval Error (TIErms), Allan variance, etc.) can be calculated: since continuous knowledge of the function x(t) is not practically attainable, sequences of equally spaced samples $x_i = x(t_0 + i\tau_0)$ are used for this purpose.

Based on a suitable model of timing signals, a corresponding time error model can be derived, as reported in annex A.

time function: The time of a clock is the measure of ideal time t as provided by that clock. Mathematically the time function T(t) generated by a clock is defined as:

$$T(t) = \frac{\Phi(t)}{2\pi v_{nom}}$$

where: $\Phi(t)$ is the total instantaneous phase of the timing signal at the clock output;
v_{nom} is the nominal frequency of the clock.

time interval error function: The difference between the measures of a time interval as provided by that clock and by the frequency standard one. Mathematically, the time interval error function TIE(t:τ) can be expressed in terms of the time error function x(t) between the two clocks as:

$$\mathrm{TIE}(t:\tau) = x(t+\tau) - x(t)$$

where: t is the initial instant of observation;
τ is the observation interval.

Time Variance (TVAR or $\sigma_x^2(\tau)$): The square of the time deviation.

timing signal: A nominally periodic signal, generated by a clock, used to control the timing of operations in digital equipments and networks. Due to unavoidable disturbances, such as oscillator phase fluctuations, actual timing signals are pseudo-periodic ones, i.e. time intervals between successive equal phase instants show slight variations. Mathematically a timing signal s(t) is represented by:

$$s(t) = A \times \sin[\Phi(t)]$$

where: A is a constant amplitude coefficient;
Φ(t) is the total instantaneous phase (Φ(t) is modelled as reported in annex A).

3.1.6 Synchronous Digital Hierarchy (SDH) specific definitions

SDH Equipment Clock (SEC): The logical function representing the equipment clock of a SDH network element having the timing characteristics given in EN 300 462-5-1 [4].

SDH Equipment Timing Source (SETS): A logical function representing all synchronization related functions to be considered in an SDH network element.

synchronization node: A synchronization node consists of an SSU and all co-located SECs directly synchronized from that SSU.

3.2 Abbreviations

For the purposes of the present document, the following abbreviations apply:

ADEV	Allan DEViation
AIS	Alarm Indication Signal
AP	Access Point
AU	Administrative Unit
BIPM	Bureau International des Poids et Mesures
CMI	Code Mark Inversion
CUT	Clock Under Test
FFM	Flicker Frequency Modulation noise
FPM	Flicker Phase Modulation noise
IERS	International Earth Rotation Service
ITU-T	International Telecommunication Union-Telecommunication Standardisation Sector
MDEV	Modified Allan DEViation
MC	Master Clock
MRTIE	Maximum Relative Time Interval Error
MST	Multiplex Section Termination
MTIE	Maximum Time Interval Error
NE	Network Element
PDH	Plesiochronous Digital Hierarchy
PLL	Phase Locked Loop
ppm	parts per million
PRC	Primary Reference Clock
PSTN	Public Switched Telephone Network
rms	root mean square

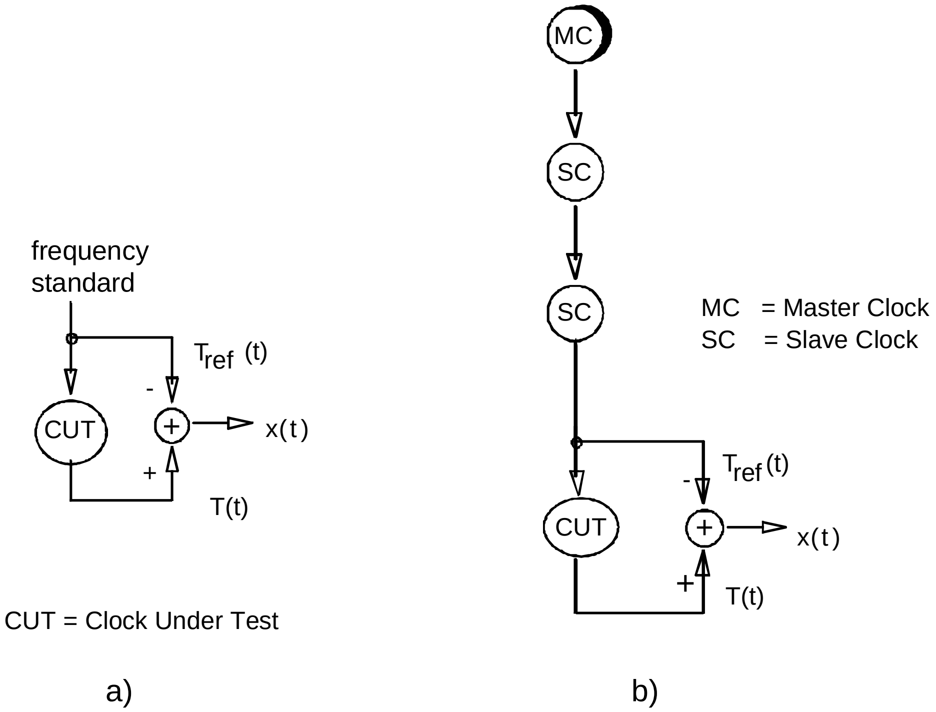
RWFM	Random Walk Frequency Modulated noise
SC	Slave Clock
SASE	Stand Alone Synchronization Equipment
SDH	Synchronous Digital Hierarchy
SEC	SDH Equipment Clock
SETS	SDH Equipment Timing Source
STM	Synchronous Transport Module
SSU	Synchronization Supply Unit
TDEV	Time DEViation
TIE	Time Interval Error
TIErms	root mean square Time Interval Error
TM	Transmission and Multiplexing
TU	Tributary Unit
TVAR	Time VARiance
UI	Unit Interval
UIp-p	Unit Interval peak-to-peak
UTC	Universal Time Coordinated
VC	Virtual Container
VCO	Voltage Control Oscillator
WFM	White Frequency Modulation noise
WPM	White Phase Modulation noise

4 Measurement configurations

When measuring the performance of clocks, the measurement configuration will influence the test results. Consequently all specifications in the present multi-part document should specify one of the following measurement configurations.

4.1 Synchronized clock measurement configuration

When the two timing signals involved in the measurement of time error are traceable to a common master clock, the measurement configuration is referred to as synchronized clock configuration. Two cases of practical interest where this configuration applies are shown in figure 1. The time error measured in synchronized clock configuration is unaffected by frequency offset and drift of the common master clock, as shown in annex A. Stability parameters calculated from such time error values reflect only internal phase noise of clocks involved in the measurement.

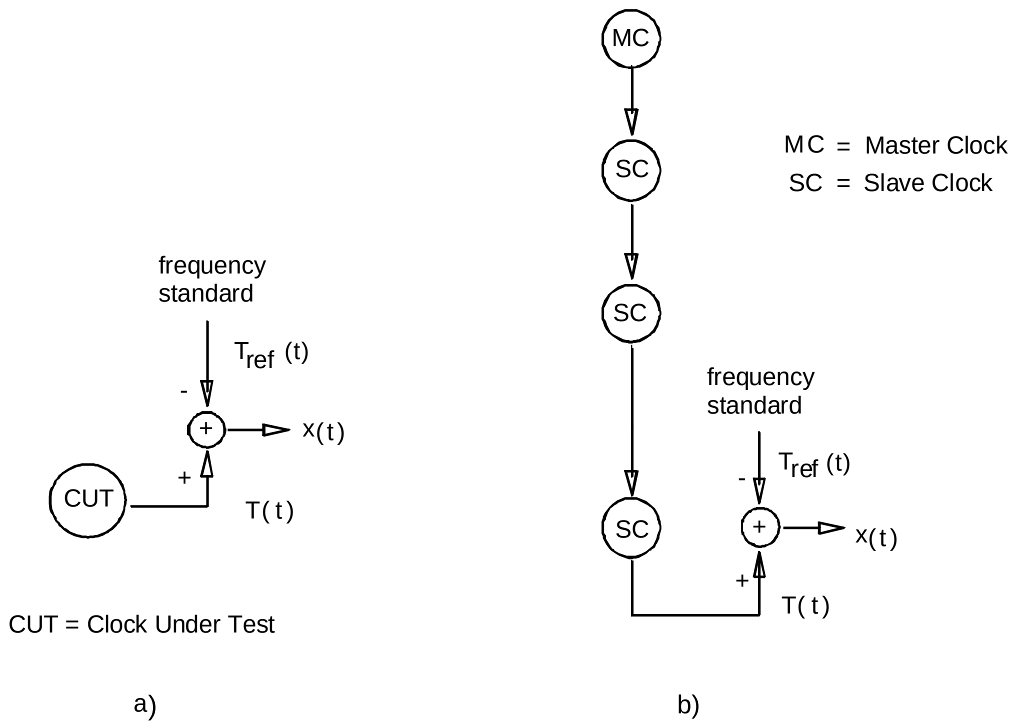


a) In-lab locked mode clock characterization.
b) In the field locked mode clock characterization.

Figure 1: Examples of time error measurement in a synchronized clock configuration

4.2 Independent clock measurement configuration

Any situation where there is no common master clock controlling the timing signals between which the time error is measured, is referred to as independent clock configuration. Examples where this configuration applies are shown in figure 2. The time error measured in an independent clock configuration, besides being dependent on internal clock noise, is affected by any frequency offset or frequency drift of the clocks involved in the measurement.



a) In-lab free-running clock characterization.
b) Synchronization interface characterization.

Figure 2: Examples of time error measurement in an independent clock configuration

Annex A (normative): Mathematical models of timing signals

A.1 Total instantaneous phase model of an ideal timing signal

The total phase Φ(t) of an ideal timing signal is modelled as follows:

$$\Phi_{nom}(t) = 2\pi v_{\mathrm{nom}} t$$

where: v_{nom} is called the nominal frequency.

A.2 Total instantaneous phase model of actual timing signals

In actual timing signals Φ(t) is modelled as:

$$\Phi(t) = \Phi_0 + 2\pi v_{\mathrm{nom}}(1 + y_0)t + \pi D v_{\mathrm{nom}} t^2 + \varphi(t)$$

where: Φ_0 is the initial phase offset, y_0 is the fractional frequency offset from the nominal value v_{nom} (mainly due to finite frequency settability of the clock);

D is the linear fractional frequency drift rate (basically representing oscillator ageing effects);

φ(t) is the random phase deviation component.

A.3 Time error model

Based on the definition of time error and the above model of Φ(t), the following model for x(t) results:

$$x(t) = x_0 + (y_0 - y_{0,\mathrm{ref}})t + \frac{D - D_{\mathrm{ref}}}{2} t^2 + \frac{\varphi(t) - \varphi_{\mathrm{ref}}(t)}{2\pi v_{\mathrm{nom}}}$$

NOTE: Some authors denote by x(t) the random noise component only (i.e. the last term in the above equation), while in our terminology x(t) represents the whole time error including deterministic components.

Assuming that for the measurement of x(t) the independent clock configuration applies and that the measurement reference timing signal is properly chosen (i.e. all its degradation sources ($y_{0,ref}$, D_{ref} and $\varphi_{ref}(t)$) are negligible as compared to those of the clock under test), the x(t) model reduces to:

$$x(t) = x_0 + y_0 t + \frac{D}{2} t^2 + \frac{\varphi(t)}{2\pi v_{\mathrm{nom}}}$$

When the synchronized clock configuration applies and all slave clocks involved in the distribution of timing (including the clock under test) are operating in locked mode, $y_{0,ref} = y_0$ and $D_{ref} = D$ can be assumed; the x(t) model then reduces to:

$$x(t) = x_0 + \frac{\varphi(t) - \varphi_{\mathrm{ref}}(t)}{2\pi v_{\mathrm{nom}}}$$

Annex B (informative): Definitions and properties of frequency and time stability quantities

At present, five quantities are considered of interest in standardization bodies for characterization of time stability:

- the Allan Deviation (ADEV);
- the Modified ADEV (MDEV);
- the Time Deviation (TDEV);
- the root mean square of Time Interval Error (TIErms);
- the Maximum Time Interval Error (MTIE).

In clauses B.1 to B.5, the various stability quantities are characterized according to the above scheme.

- The formal definition in terms of the Time Error function x(t);
- the estimator expression in terms of a sampled version of x(t), i.e. in terms of the sequence of N values $x_i = x(i\tau_0)$, where τ_0 is the sampling period and i = 1, 2, ..., N;
- the integral time-domain/frequency-domain relationship between the power spectral density $S\varphi(f)$ of the random phase deviation $\varphi(t)$ affecting a timing signal and the considered quantity;
- the quantity behaviour when the timing signal is affected by noise of the most common types, namely, White Phase Modulation (WPM), Flicker Phase Modulation (FPM), White Frequency Modulation (WFM), Flicker Frequency Modulation (FFM) and Random Walk Frequency Modulation (RWFM);
- the quantity behaviour when the timing signal is affected by frequency offset and drift;
- pros and cons, as well as technical information, on the measurement set-up and on the usefulness in designing synchronization networks.

As far as the formal definitions of ADEV and MDEV in terms of x(t) are concerned, the x(t) function takes into account random noise effects only, while here, for practical reasons and without loss of generality, it is assumed that x(t) includes also deterministic components, if any.

B.1 Allan deviation (ADEV)

In the following, x(t) is the time error function, $\{x_i = x(i\tau_0), i = 1,2,...,N\}$ is a sequence of N equally spaced samples of x(t), τ_0 is the sampling period and $\tau = n\tau_0$ is the observation interval.

Definition:

The Allan deviation ADEV(τ) is defined as:

$$\mathrm{ADEV}(\tau) = \sqrt{\frac{1}{2\tau^2}\left\langle\left[x(t+2\tau) - 2x(t+\tau) + x(t)\right]^2\right\rangle},$$

where the angle brackets denote an ensemble average.

Estimator formula:

$\mathrm{ADEV}(n\tau_0)$ can be estimated by:

$$\mathrm{ADEV}(n\tau_0) \cong \sqrt{\frac{1}{2n^2\tau_0^2(N-2n)}\sum_{i=1}^{N-2n}\left(x_{i+2n}-2x_{i+n}+x_i\right)^2} \quad , \quad n = 1, 2, \ldots, \text{integer part}\left[\frac{(\mathrm{N}-1)}{2}\right]$$

Integral frequency-domain/time-domain relationship:

The Allan deviation of a timing signal is related to the power spectral density $S\varphi(f)$ of its random phase deviation $\varphi(t)$ by the following integral relationship:

$$\mathrm{ADEV}(\tau) = \sqrt{\frac{2}{(\pi \nu_{nom}\tau)^2}\int_0^{f_h} S_\varphi(f)\,\sin^4(\pi\tau f)\,\mathrm{d}f} \,,$$

where ν_{nom} is the nominal frequency of the timing signal and f_h is the measurement system bandwidth. The above relationship holds under the assumption that no deterministic component affects the time error data used to compute ADEV(τ).

Noise performance:

The ADEV(τ) converges for all the major noise types affecting actual timing signals. In the table below, the characteristic slopes of ADEV(τ), for different noise types, are reported. The ADEV(τ) does not allow to discriminate between WPM and FPM noise.

Table B.1

Noise process	Slope of ADEV(t)
WPM	τ^{-1}
FPM	τ^{-1}
WFM	$\tau^{-1/2}$
FFM	τ^{0}
RWFM	$\tau^{1/2}$

Frequency offset and drift:

Any constant frequency offset of a timing signal, relative to the reference clock, has no influence on ADEV(τ).

For observation intervals τ where a linear frequency drift dominates, the ADEV(τ) behaves as τ.

Pros and cons:

The behaviour of ADEV(τ) is substantially independent of sampling period τ_0.

ADEV gives more information on the clock noise than MTIE, but it is not suited for buffer characterization.

ADEV is sensitive to systematic effects, which might mask noise components; adequate filtering must be done on the measured signal before processing ADEV calculation. Diurnal wander is an example of systematic effect.

ADEV result coming out of network measurement could be heavily influenced by systematic effects.

B.2 Modified Allan deviation (MDEV)

In the following, x(t) is the time error function, $\{x_i = x(i\tau_0), i = 1, 2, ..., N\}$ is a sequence of N equally spaced samples of x(t), τ_0 is the sampling period and $\tau = n\tau_0$ is the observation interval.

Definition:

The Modified Allan deviation $\mathrm{MDEV}(n\tau_0)$ is defined as:

$$\mathrm{MDEV}(n\tau_0) = \sqrt{\frac{1}{2(n\tau_0)^2}\left\langle\left[\frac{1}{n}\sum_{i=1}^{n}\left(x_{i+2n} - 2x_{i+n} + x_i\right)\right]^2\right\rangle},$$

where the angle brackets denote an ensemble average.

Estimator formula:

$\mathrm{MDEV}(n\tau_0)$ may be estimated by:

$$\mathrm{MDEV}(n\tau_0) \cong \sqrt{\frac{1}{2n^4\tau_0^2(N-3n+1)}\sum_{j=1}^{N-3n+1}\left[\sum_{i=j}^{n+j-1}\left(x_{i+2n} - 2x_{i+n} + x_i\right)\right]^2}, \quad n = 1, 2, ..., \text{integer part}\left[\frac{N}{3}\right]$$

Integral frequency-domain/time-domain relationship:

The modified Allan deviation of a timing signal is related to the power spectral density $S_\varphi(f)$ of its random phase deviation $\varphi(t)$ by the following integral relationship:

$$\mathrm{MDEV}(n\tau_0) = \sqrt{\frac{2}{\left(\pi\nu_{\mathrm{nom}} n^2\tau_0\right)^2}\int_0^{fh} S_\varphi(f)\ \frac{\sin^6(\pi n\tau_0 f)}{\sin^2(\pi\tau_0 f)}\ \mathrm{d}f},$$

where ν_{nom} is the nominal frequency of the timing signal and f_h is the measurement system bandwidth. The above relationship holds under the assumption that no deterministic components affects the time error data used to compute $\mathrm{MDEV}(n\tau_0)$.

Noise performance:

The $\mathrm{MDEV}(\tau)$ converges for all the major noise types affecting actual timing signals. In the table below, the characteristic slopes of $\mathrm{MDEV}(\tau)$, for different noise types, are reported, showing that $\mathrm{MDEV}(\tau)$ allows to discriminate all the five types of noise.

Table B.2

Noise process	Slope of MDEV(t)
WPM	$\tau^{-3/2}$
FPM	τ^{-1}
WFM	$\tau^{-1/2}$
FFM	τ^{0}
RWFM	$\tau^{1/2}$

Frequency offset and drift:

Any constant frequency offset of a timing signal, relative to the reference clock, has no influence on MDEV(τ).

For observation intervals τ where a linear frequency drift dominates, the MDEV(τ) behaves as τ.

Pros and cons:

For observation intervals where the WPM noise dominates, the behaviour of MDEV(τ) significantly depends on sampling period τ_0.

MDEV gives more information on the clock noise than MTIE, but it is not suited for buffer characterization.

MDEV is sensitive to systematic effects which might mask noise components; adequate filtering should be done on the measured signal before processing MDEV calculation. Diurnal wander is an example of systematic effect.

MDEV result coming out of network measurement could be heavily influenced by systematic effects.

B.3 Time deviation (TDEV)

In the following, x(t) is the time error function, $\{x_i = x(i\tau_0)$, i = 1, 2, ..., N$\}$ is a sequence of N equally spaced samples of x(t), τ_0 is the sampling period and $\tau = n\tau_0$ is the observation interval.

Definition:

The Time deviation TDEV($n\tau_0$) is defined as:

$$\mathrm{TDEV}(n\tau_0) = \sqrt{\frac{1}{6n^2}\left\langle \left[\sum_{i=1}^{n} \left(x_{i+2n} - 2x_{i+n} + x_i \right) \right]^2 \right\rangle} = \frac{n\tau_0}{\sqrt{3}} \mathrm{MADEV}(n\tau_0),$$

where the angle brackets denote an ensemble average.

Estimator formula:

TDEV($n\tau_0$) may be estimated by:

$$\mathrm{TDEV}(n\tau_0) = \sqrt{\frac{1}{6n^2(N-3n+1)} \sum_{j=1}^{N-3n+1} \left[\sum_{i=j}^{n+j-1} \left(x_{i+2n} - 2x_{i+n} + x_i \right) \right]^2} , \quad n = 1,\ 2,\ \ldots,\ \text{integer part}\left[\frac{N}{3}\right]$$

Integral frequency-domain/time-domain relationship:

The Time deviation of a timing signal is related to the power spectral density $S_\varphi(f)$ of its random phase deviation $\varphi(t)$ by the following integral relationship:

$$\mathrm{TDEV}(\tau) = \sqrt{\frac{2}{3(\pi \nu_{nom} n)^2} \int_0^{f_h} S_\varphi(f) \, \frac{\sin^6(\pi n \tau_0 f)}{\sin^2(\pi \tau_0 f)} \, df} ,$$

where ν_{nom} is the nominal frequency of the timing signal and f_h is the measurement system bandwidth. The above relationship holds under the assumption that no deterministic components affects the time error data used to compute TDEV($n\tau_0$).

Approximate time-domain/frequency-domain relationship:

The Time deviation of a timing signal and its relation to the power spectral density $S_\varphi(f)$ of its random phase deviation $\varphi(t)$ can be approximated by the following simple relationship:

$$\mathrm{TDEV}(\tau) \approx \sqrt{\frac{1}{2{,}5\tau} S\varphi\left(\frac{0{,}3}{\tau}\right)}$$

That is, when $S_\varphi(f)$ is known, substitute $0{,}3/\tau$ for f, divide by $2{,}5\tau$, and take the square root.

More usefully, since no exact closed-form expression can be defined, the reverse relationship can also be simply approximated:

$$S\varphi(f) \approx \frac{0{,}75}{f}\left(\mathrm{TDEV}\left(\frac{0{,}3}{f}\right)\right)^2$$

The above equation may be applied to obtain the equivalent power spectral density of TDEV characteristics, for example when determining the noise transfer characteristic of a synchronization element in the frequency domain.

Noise performance:

The TDEV(τ) converges for all the major noise types affecting actual timing signals. In the table below, the characteristic slopes of TDEV(τ), for different noise types, are reported. The TDEV(τ) allows to discriminate between all the five types of noise.

Table B.3

Noise process	Slope of TDEV(t)
WPM	$\tau^{-1/2}$
FPM	τ^{0}
WFM	$\tau^{1/2}$
FFM	τ
RWFM	$\tau^{3/2}$

Frequency offset and drift:

Any constant frequency offset of a timing signal, relative to the reference clock, has no influence on TDEV(τ).

For observation intervals τ where a linear frequency drift dominates, the TDEV(τ) behaves as τ^2.

Pros and cons:

For observation intervals where the WPM noise dominates, the behaviour of TDEV(τ) significantly depends on sampling period τ_0.

TDEV gives more information on the clock noise than MTIE, but it is not suited for buffer characterization.

TDEV is sensitive to systematic effects, which might mask noise components; adequate filtering should be done on the measured signal before processing TDEV calculation. Diurnal wander is an example of systematic effect.

TDEV result coming out of network measurement could be heavily influenced by systematic effects.

B.4 Root mean square Time Interval Error (TIErms)

In the following, x(t) is the time error function, $\{x_i = x(i\tau_0), i = 1, 2, ..., N\}$ is a sequence of N equally spaced samples of x(t), τ_0 is the sampling period and $\tau = n\tau_0$ is the observation interval.

Definition:

The root mean square time interval error TIErms(τ) is defined as:

$$\mathrm{TIErms}(\tau) = \sqrt{\left\langle \left[x(t+\tau) - x(t) \right]^2 \right\rangle} \, ,$$

where the angle brackets denote an ensemble average.

Estimator formula:

TIErms($n\tau_0$) can be estimated by:

$$\mathrm{TIErms}(n\tau_0) = \sqrt{\frac{1}{N-n}\sum_{i=1}^{N-n}\left(x_{i+n} - x_i\right)^2} \quad , \qquad n = 1,\ 2,\ \ldots,\ (N-1)$$

Integral frequency-domain/time-domain relationship:

The root mean square time interval error of a timing signal is related to the power spectral density Sφ(f) of its random phase deviation φ(t) by the following integral relationship:

$$\mathrm{TIErms}(\tau) = \sqrt{\frac{1}{(\nu_{nom}\tau)^2}\int_0^{f_h} S_\varphi(f)\,\sin^2(\pi\tau f)\,df} \, ,$$

where ν_{nom} is the nominal frequency of the timing signal and f_h is the measurement system bandwidth. The above relationship holds under the assumption that no deterministic components affects the time error data used to compute TIErms(τ).

Noise performance:

The TIErms(τ) does not theoretically converges in the presence of FFM and RWFM noises. In the table below, the characteristic slopes of TIErms(τ), for different noise types, are reported.

Table B.4

Noise process	Slope of TIErms(t)
WPM	τ^0
FPM	τ^0
WFM	$\tau^{1/2}$

Frequency offset and drift:

For observation intervals τ where the constant frequency offset dominates, the TIErms(τ) behaves as τ.

For observation intervals τ where a linear frequency drift dominates, the TIErms(τ) does not theoretically converge to a finite value. From the measurement viewpoint this circumstance is expected to cause increasing value of estimated TIErms(τ) as the number N of x_i samples, and hence the total averaging time, is increased.

Pros and cons:

The behaviour of TIErms(τ) is substantially independent of sampling period τ_0.

B.5 Maximum Time Interval Error (MTIE)

In the following, x(t) is the time error function, $\{x_i = x(i\tau_0),\ i = 1, 2, ..., N\}$ is a sequence of N equally spaced samples of x(t), τ_0 is the sampling period and $\tau = n\tau_0$ is the observation interval.

Definition:

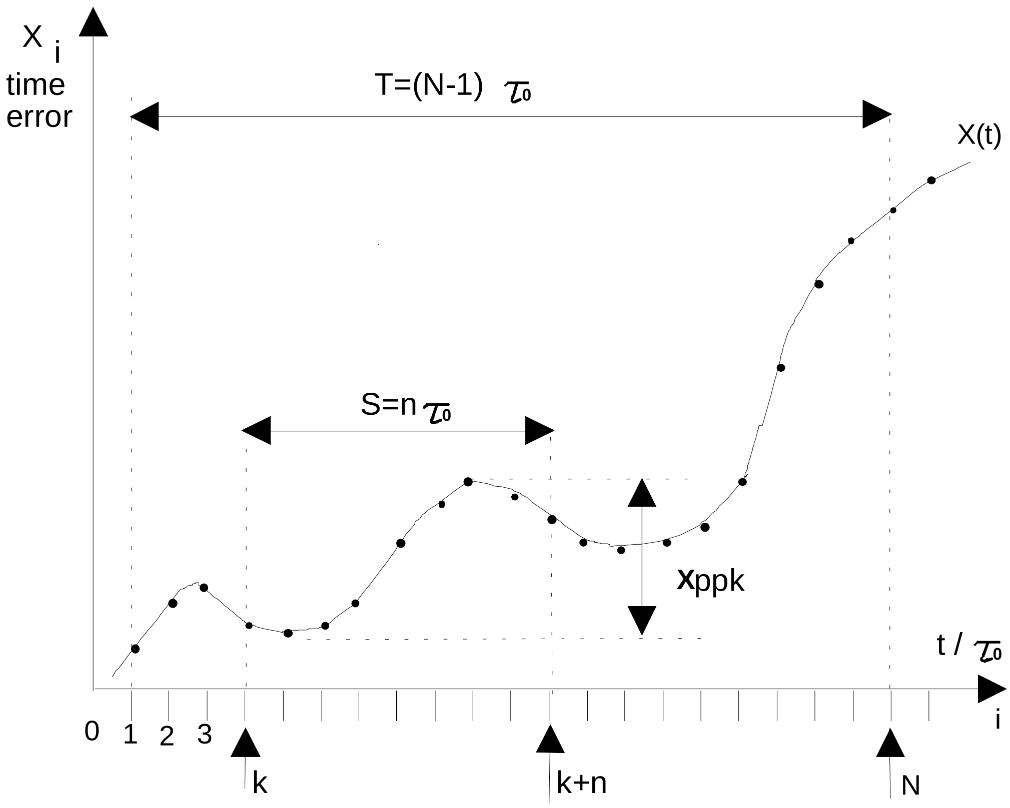
The maximum time interval error MTIE(τ) is defined as:

$$\mathrm{MTIE}(\tau) = \max_{-\infty \le t_0 \le \infty} \left(\max_{t_0 \le t \le t_0+\tau} [x(t)] - \min_{t_0 \le t \le t_0+\tau} [x(t)] \right)$$

Estimator formula:

MTIE($n\tau_0$) can be estimated by:

$$\mathrm{MTIE}(n\tau_0) = \max_{1 \le k \le N-n} \left(\max_{k \le i \le k+n} (x_i) - \min_{k \le i \le k+n} (x_i) \right), \quad n = 1, 2, \ldots, (N-1)$$



where: τ_0 = time error sampling period;
S = observation time;
T = measurement period;
X_j = time error sample;
X_{ppk} =peak to peak time error difference in one observation time interval;
MTIE(S) = maximum X_{ppk} for all observations of length S within T.

Figure B.1

Frequency offset and drift:

For observation intervals τ where the constant frequency offset dominates, the MTIE(τ) behaves as τ.

For observation intervals τ where a linear frequency drift dominates, the MTIE(τ) is not theoretically bounded. From the measurement viewpoint, this circumstance is expected to cause increasing value of estimated MTIE(τ) as the total observation time, (i.e. the length N of the x_i data) is increased.

Pros and cons:

The behaviour of MTIE(τ) is substantially independent of sampling period τ_0.

MTIE (and MRTIE) is well suited for characterization of buffer size.

Annex C (informative): Bibliography

The following reference is given for informative purposes:

- D.A. Howe, D.W. Allan, J. A. Barnes, "Properties of signal sources and measurement methods", Proc. of the 35th Annual Symposium on Frequency Control, 1981.

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