International Telecommunication Union

ITU-T

TELECOMMUNICATION STANDARDIZATION SECTOR OF ITU

G.8262.1/Y.1362.1

Amendment 1

(08/2019)

SERIES G: TRANSMISSION SYSTEMS AND MEDIA, DIGITAL SYSTEMS AND NETWORKS

Packet over Transport aspects – Synchronization, quality and availability targets

SERIES Y: GLOBAL INFORMATION INFRASTRUCTURE, INTERNET PROTOCOL ASPECTS, NEXT-GENERATION NETWORKS, INTERNET OF THINGS AND SMART CITIES

Internet protocol aspects – Transport

Timing characteristics of enhanced synchronous equipment slave clock

Amendment 1

Recommendation ITU-T G.8262.1/Y.1362.1 (2019) – Amendment 1

ITU-T G-SERIES RECOMMENDATIONS

TRANSMISSION SYSTEMS AND MEDIA, DIGITAL SYSTEMS AND NETWORKS

INTERNATIONAL TELEPHONE CONNECTIONS AND CIRCUITS	G.100–G.199
GENERAL CHARACTERISTICS COMMON TO ALL ANALOGUE CARRIER-TRANSMISSION SYSTEMS	G.200–G.299
INDIVIDUAL CHARACTERISTICS OF INTERNATIONAL CARRIER TELEPHONE SYSTEMS ON METALLIC LINES	G.300–G.399
GENERAL CHARACTERISTICS OF INTERNATIONAL CARRIER TELEPHONE SYSTEMS ON RADIO-RELAY OR SATELLITE LINKS AND INTERCONNECTION WITH METALLIC LINES	G.400–G.449
COORDINATION OF RADIOTELEPHONY AND LINE TELEPHONY	G.450–G.499
TRANSMISSION MEDIA AND OPTICAL SYSTEMS CHARACTERISTICS	G.600–G.699
DIGITAL TERMINAL EQUIPMENTS	G.700–G.799
DIGITAL NETWORKS	G.800–G.899
DIGITAL SECTIONS AND DIGITAL LINE SYSTEM	G.900–G.999
MULTIMEDIA QUALITY OF SERVICE AND PERFORMANCE – GENERIC AND USER-RELATED ASPECTS	G.1000–G.1999
TRANSMISSION MEDIA CHARACTERISTICS	G.6000–G.6999
DATA OVER TRANSPORT – GENERIC ASPECTS	G.7000–G.7999
PACKET OVER TRANSPORT ASPECTS	G.8000–G.8999
Ethernet over Transport aspects	G.8000–G.8099
MPLS over Transport aspects	G.8100–G.8199
Synchronization, quality and availability targets	**G.8200–G.8299**
Service Management	G.8600–G.8699
ACCESS NETWORKS	G.9000–G.9999

For further details, please refer to the list of ITU-T Recommendations.

Recommendation ITU-T G.8262.1/Y.1362.1

Timing characteristics of enhanced synchronous equipment slave clock

Amendment 1

Summary

Recommendation ITU-T G.8262.1/Y.1362.1 outlines requirements for timing devices used in synchronizing network equipment that uses the physical layer to deliver frequency synchronization. This Recommendation defines the requirements for clocks, e.g., bandwidth, frequency accuracy, holdover and noise generation.

Amendment 1 provides the following updates:

- Adds requirements for clause 9.1
- Replaces clause 9.3.1 with a reference to clause 9.2.1 of Recommendation ITU-T G.8262/Y.1362
- Adds "enhanced" to the "synchronous OTN interface" in clause 9.3.3
- Changes in clause 11.1: defines parameter *S*; defines parameter *T* (except for OTN interfaces)
- Changes in clause 11.2: define parameter a_2; changes Figure 8 to start at 15 s
- Adds "Synchronous OTN interfaces" in clause 12
- Adds text to Appendix IV
- Adds Appendix V

History

Edition	Recommendation	Approval	Study Group	Unique ID*
1.0	ITU-T G.8262.1/Y.1362.1	2019-01-12	15	11.1002/1000/13850
1.1	ITU-T G.8262.1/Y.1362.1 (2019) Amd. 1	2019-08-29	15	11.1002/1000/14011

* To access the Recommendation, type the URL http://handle.itu.int/ in the address field of your web browser, followed by the Recommendation's unique ID. For example, http://handle.itu.int/11.1002/1000/11830-en.

FOREWORD

The International Telecommunication Union (ITU) is the United Nations specialized agency in the field of telecommunications, information and communication technologies (ICTs). The ITU Telecommunication Standardization Sector (ITU-T) is a permanent organ of ITU. ITU-T is responsible for studying technical, operating and tariff questions and issuing Recommendations on them with a view to standardizing telecommunications on a worldwide basis.

The World Telecommunication Standardization Assembly (WTSA), which meets every four years, establishes the topics for study by the ITU-T study groups which, in turn, produce Recommendations on these topics.

The approval of ITU-T Recommendations is covered by the procedure laid down in WTSA Resolution 1.

In some areas of information technology which fall within ITU-T's purview, the necessary standards are prepared on a collaborative basis with ISO and IEC.

NOTE

In this Recommendation, the expression "Administration" is used for conciseness to indicate both a telecommunication administration and a recognized operating agency.

Compliance with this Recommendation is voluntary. However, the Recommendation may contain certain mandatory provisions (to ensure, e.g., interoperability or applicability) and compliance with the Recommendation is achieved when all of these mandatory provisions are met. The words "shall" or some other obligatory language such as "must" and the negative equivalents are used to express requirements. The use of such words does not suggest that compliance with the Recommendation is required of any party.

INTELLECTUAL PROPERTY RIGHTS

ITU draws attention to the possibility that the practice or implementation of this Recommendation may involve the use of a claimed Intellectual Property Right. ITU takes no position concerning the evidence, validity or applicability of claimed Intellectual Property Rights, whether asserted by ITU members or others outside of the Recommendation development process.

As of the date of approval of this Recommendation, ITU had not received notice of intellectual property, protected by patents, which may be required to implement this Recommendation. However, implementers are cautioned that this may not represent the latest information and are therefore strongly urged to consult the TSB patent database at http://www.itu.int/ITU-T/ipr/.

Table of Contents

Introduction

The synchronization method refers to the primary reference clock (PRC) distributed method (for instance, based on the global navigation satellite system (GNSS)), or the master-slave method using a synchronous physical layer (e.g., ETY, STM-N). These methods are widely implemented to synchronize the TDM networks.

Recommendation ITU-T G.8262.1/Y.1362.1

Timing characteristics of enhanced synchronous equipment slave clock

Amendment 1

Editorial note: This is a complete-text publication. Modifications introduced by this amendment are shown in revision marks relative to Recommendation ITU-T G.8262.1/Y.1362.1 (2019).

1 Scope

This Recommendation outlines new requirements for timing devices used in synchronizing network equipment that supports synchronous clocks, involved in time and phase transport. It supports clock distribution based on network-synchronous line-code methods (e.g., synchronous Ethernet, synchronous optical transport network (OTN) to deliver frequency synchronization).

This Recommendation focuses on the requirements for the enhanced synchronous Ethernet equipment clock (eEEC) and the enhanced synchronous OTN equipment clock (eOEC).

This Recommendation allows for proper network operation when this clock is timed from another network equipment clock or a higher-quality clock.

Included in this Recommendation are requirements for clock accuracy, noise transfer, holdover performance, noise tolerance and noise generation. These requirements apply under the normal environmental conditions specified for the equipment.

This Recommendation contains a single option for enhanced synchronous equipment clock. The networks containing enhanced synchronous equipment clock allow the worst-case synchronization reference chain as specified in Figure 8-5 of [ITU-T G.803].

Careful consideration should be taken when using both ITU-T G.8262.1 and ITU-T G.8262 clocks in the same chain as this may lead to not meeting the performance required by the relevant time and phase synchronization application. The highest performance can be achieved in networks where only enhanced synchronous equipment clocks ~~EEC~~ or better clocks are implemented, see [ITU-T G.8261] for the applicable network limits.

OTN 3R regenerators, as specified in [ITU-T G.8251], provide through-timing capability and can transmit timing via synchronous OTN.

More information on synchronous Ethernet can be found in [ITU-T G.781], [ITU-T G.8261] and [ITU-T G.8264], and for synchronous OTN can be found in [ITU-T G.709] and [ITU-T G.7041].

NOTE – The clock specified in this Recommendation is compatible with the Option 1 clock specified in [ITU-T G.8262].

2 References

The following ITU-T Recommendations and other references contain provisions which, through reference in this text, constitute provisions of this Recommendation. At the time of publication, the editions indicated were valid. All Recommendations and other references are subject to revision; users of this Recommendation are therefore encouraged to investigate the possibility of applying the most recent edition of the Recommendations and other references listed below. A list of the currently valid ITU-T Recommendations is regularly published. The reference to a document within this Recommendation does not give it, as a stand-alone document, the status of a Recommendation.

[ITU-T G.703] Recommendation ITU-T G.703 (2001), *Physical/electrical characteristics of hierarchical digital interfaces*.

[ITU-T G.709] Recommendation ITU-T G.709/Y.1331 (2016), *Interfaces for the optical transport network*.

[ITU-T G.781] Recommendation ITU-T G.781 (2017), *Synchronization layer functions*.

[ITU-T G.803] Recommendation ITU-T G.803 (2000), *Architecture of transport networks based on the synchronous digital hierarchy (SDH)*.

[ITU-T G.810] Recommendation ITU-T G.810 (1996), *Definitions and terminology for synchronization networks*.

[ITU-T G.811] Recommendation ITU-T G.811 (1997), *Timing characteristics of primary reference clocks*.

[ITU-T G.812] Recommendation ITU-T G.812 (2004), *Timing requirements of slave clocks suitable for use as node clocks in synchronization networks*.

[ITU-T G.813] Recommendation ITU-T G.813 (2003), *Timing characteristics of SDH equipment slave clocks (SEC)*.

[ITU-T G.825] Recommendation ITU-T G.825 (2000), *The control of jitter and wander within digital networks which are based on the synchronous digital hierarchy (SDH)*.

[ITU-T G.7041] Recommendation ITU-T G.7041/Y.1303 (2016), *Generic framing procedure*.

[ITU-T G.8251] Recommendation ITU-T G.8251 (2018), *The control of jitter and wander within the optical transport network (OTN)*.

[ITU-T G.8261] Recommendation ITU-T G.8261/Y.1361 (2013), *Timing and synchronization aspects in packet networks*.

[ITU-T G.8262] Recommendation ITU-T G.8262/Y.1362 (2018), *Timing characteristics of synchronous Ethernet equipment slave clock*.

[ITU-T G.8264] Recommendation ITU-T G.8264/Y.1364 (2017), *Distribution of timing information through packet networks.*

[ITU-T G.8272] Recommendation ITU-T G.8272 (2018), *Timing characteristics of primary reference time clocks*.

[IEEE 802.3] IEEE Standard 802.3-2018, *IEEE Standard for Ethernet.*

3 Definitions

The terms and definitions used in this Recommendation are contained in [ITU-T G.810].

4 Abbreviations and acronyms

This Recommendation uses the following abbreviations and acronyms:

EEC synchronous Ethernet Equipment Clock

eEEC enhanced synchronous Ethernet Equipment Clock

ESMC Ethernet Synchronization Message Channel

ETH Ethernet MAC layer network

ETY Ethernet PHY layer network

GNSS Global Navigation Satellite System

MTIE Maximum Time Interval Error

NE Network Element

OAM	Operation, Administration and Maintenance
eOEC	enhanced OTN Equipment Clock
OTN	Optical Transport Network
PRC	Primary Reference Clock
PRTC	Primary Reference Time Clock
SDH	Synchronous Digital Hierarchy
eSEC	enhanced Synchronous Equipment Clock
SSM	Synchronization Message Channel
SSU	Synchronization Supply Unit
STM	Synchronous Transport Module
TDEV	Time Deviation
UI	Unit Interval
UTC	Coordinated Universal Time

5 Conventions

eSEC: enhanced synchronous equipment clock is a generic term used for clocks defined in this Recommendation.

6 Frequency accuracy

Under free-running conditions, the enhanced equipment clock output frequency accuracy should not be greater than 4.6 ppm with regard to a reference traceable to an ITU-T G.811 or ITU-T G.8272 clock.

NOTE – The time interval for this accuracy is for further study. Values of one month and one year have been proposed.

7 Pull-in, hold-in and pull-out ranges

7.1 Pull-in range

The minimum pull-in range should be ±4.6 ppm, whatever the internal oscillator frequency offset may be.

7.2 Hold-in range

The hold-in range for enhanced equipment clock is not required.

7.3 Pull-out range

The pull-out range is for further study. A minimum value of ±4.6 ppm has been proposed.

8 Noise generation

The noise generation of an enhanced equipment clock represents the amount of phase noise produced at the output when there is an ideal input reference signal or the clock is in holdover state. A suitable reference, for practical testing purposes, implies a performance level at least 10 times more stable than the output requirements. The ability of the clock to limit this noise is described by its frequency stability. The measures maximum time interval error (MTIE) and time deviation (TDEV) are useful for characterization of noise generation performance.

MTIE and TDEV are measured through an equivalent 10-Hz, first-order, low-pass measurement filter, at a maximum sampling time τ_0 of 1/30 seconds. The minimum measurement period for TDEV is twelve times the integration period ($T = 12\tau$).

8.1 Wander in locked mode

When the enhanced equipment clock is in the locked mode of operation synchronized to a wander-free reference, the MTIE measured using the synchronized clock configuration defined in Figure 1a of [ITU-T G.810] should have the limits in Table 1, if the temperature is constant (within ±1°K):

Table 1 – Wander generation (MTIE) with constant temperature

MTIE limit [ns]	Observation interval τ [s]
$10\tau^{0.155}$	$0.1 \leq \tau \leq 1$
$10\tau^{0.1}$	$1 < \tau \leq 100$
$6.3\tau^{0.2}$	$100 < \tau \leq 1000$

The resultant requirement is shown by the thick solid line in Figure 1.

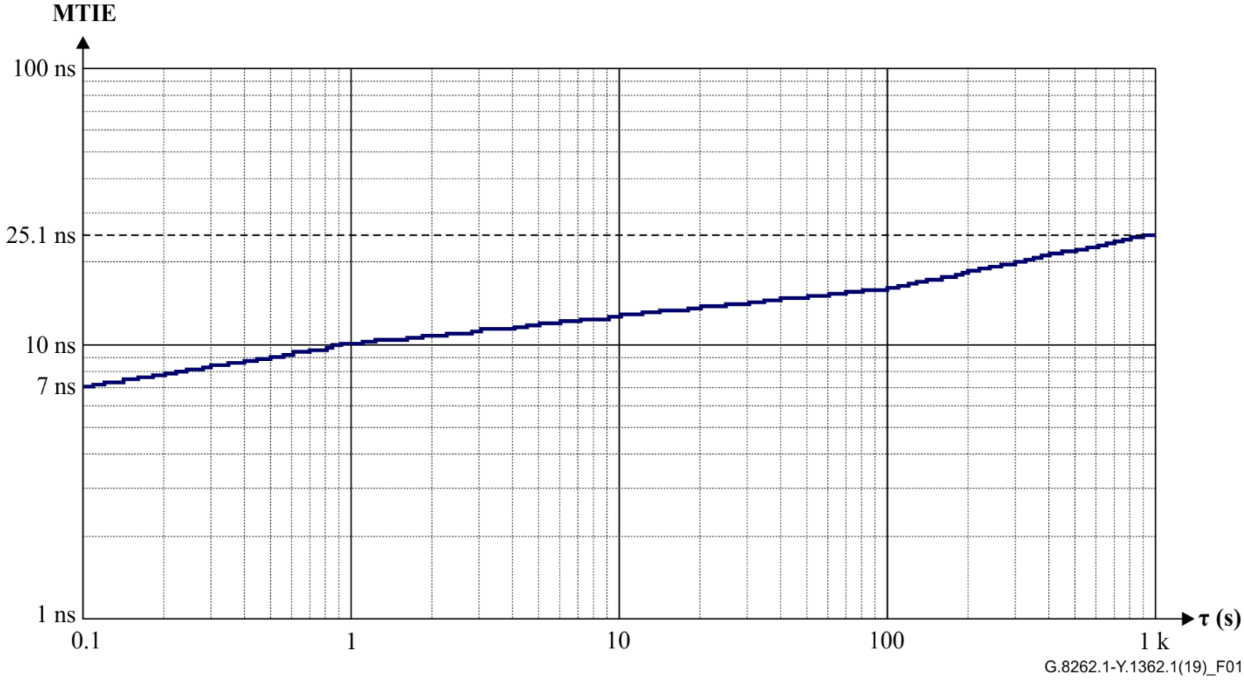


Figure 1 – Wander generation (MTIE) with constant temperature

When the enhanced equipment clock is in the locked mode of operation, the TDEV measured using the synchronized clock configuration defined in Figure 1a of [ITU-T G.810] should have the limits in Table 2, if the temperature is constant (within ±1°K):

Table 2 – Wander generation (TDEV) with constant temperature

TDEV limit [ns]	Observation interval τ [s]
0.64	$0.1 \leq \tau \leq 25$
$0.128\tau^{0.5}$	$25 < \tau \leq 100$
1.28	$100 < \tau \leq 1000$

The resultant requirements are shown in Figure 2.

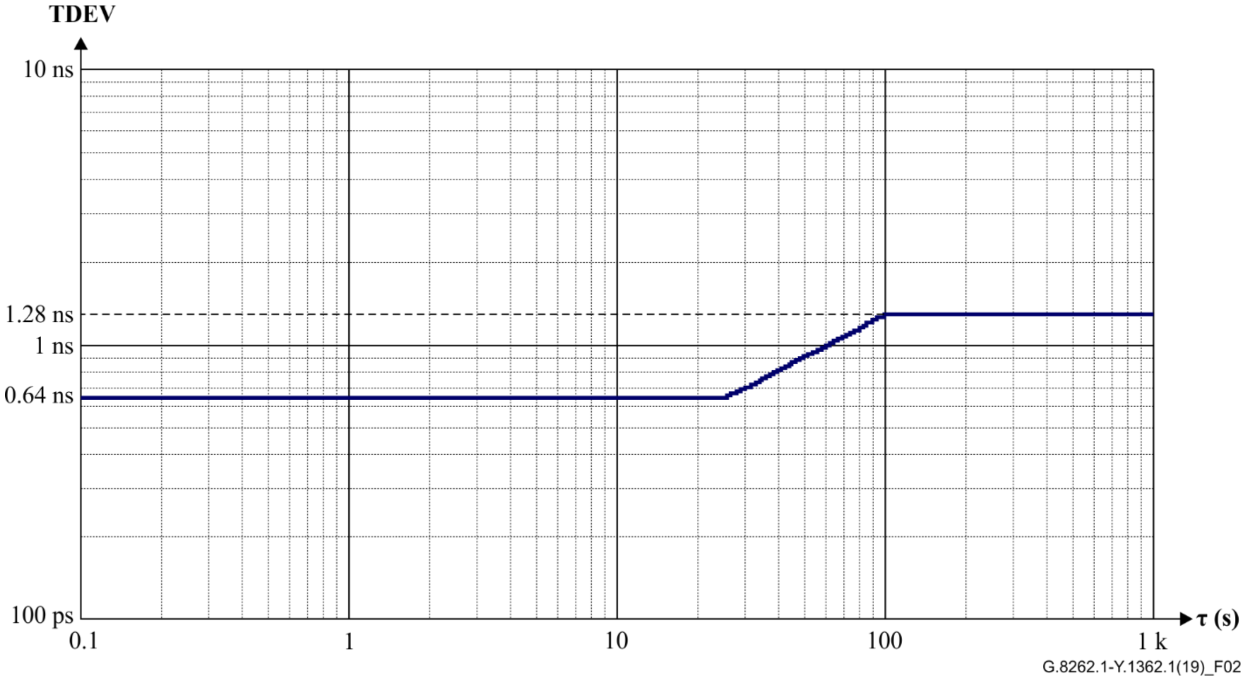


Figure 2 – Wander generation (TDEV) with constant temperature

8.2 Non-locked wander

Non-locked wander is for further study.

8.3 Jitter

While most requirements in this Recommendation are independent of the output interface at which they are measured, this is not the case for jitter production; jitter generation requirements utilize existing Recommendations that have different limits for different interface rates. These requirements are stated separately for the interfaces identified in clause 12.

8.3.1 eEEC jitter generation

Output jitter at a synchronous Ethernet interface:

In the absence of input jitter at the synchronization interface, the intrinsic jitter at the synchronous Ethernet output interfaces, as measured over a 60-second interval, should not exceed the limits given in Table 3.

Table 3 – Synchronous Ethernet jitter generation for eEEC

Interface	Measuring filter	Peak-to-peak amplitude (UI)
1G (Notes 1, 2, 3)	2.5 kHz to 10 MHz	0.50
NOTE 1 – There is no specific high-band jitter requirement for synchronous Ethernet. The relevant IEEE 802.3 jitter requirements shall be met in addition to the specific synchronous Ethernet wideband jitter requirements specified in this table. [IEEE 802.3] defines measurement methodologies. The applicability for those measurement methodologies in a synchronization network environment is for further study. NOTE 2 – 1G includes 1000BASE-KX, -SX, -LX; multi-lane interfaces are for further study. NOTE 3 – 1G: (1000BASE-KX, -SX, -LX) 1 UI = 0.8 ns.		

The jitter generation for 10G and 25G interfaces is for further study.

8.3.2 Output jitter at 2048 kHz, 2048 kbit/s, 1544 kbit/s and STM-N interfaces

Jitter generation for the 2048 kHz and 2048 kbit/s interface, and for the STM-N interface are defined for Option 1 in clause 7.3 of [ITU-T G.813].

Jitter generation for the 1544-kbit/s interface and for the STM-N interfaces are defined for Option 2 in clause 7.3 of [ITU-T G.813].

8.3.3 eOEC jitter generation

Jitter generation for the synchronous OTN interface is defined in clause A.5.1 of [ITU-T G.8251].

9 Noise tolerance

This equipment specification allows for the use of synchronous equipment clock [ITU-T G.8262] and enhanced synchronous equipment clock in the same reference chain. A reference chain based on enhanced synchronous equipment clock enables higher performance frequency networks that can support improved accurate phase/time distribution.

This Recommendation defines two levels of wander tolerance. Enhanced synchronous equipment clocks with reduced wander tolerance meeting wander tolerance level 1 can only be used in reference chains where the upstream clocks are enhanced synchronous equipment clocks. Enhanced synchronous equipment clocks with higher wander tolerance meeting wander tolerance level 2 can be used in reference chains where some of the upstream clocks are synchronous equipment clock as defined in [ITU-T G.8262].

The noise tolerance of an enhanced equipment clock indicates the minimum phase noise level at the input of the clock that should be accommodated whilst:

– not causing any alarms;

– not causing the clock to switch reference;

– not causing the clock to go into holdover.

NOTE – There are no output noise requirements as part of noise tolerance requirements. The relevant specifications are defined in the noise generation and noise transfer related clauses.

The TDEV signal used for a conformance test should be generated by adding white, Gaussian noise sources, of which each has been filtered to obtain the proper type of noise process with the proper amplitude.

MTIE and TDEV are measured through an equivalent 10-Hz, first-order, low-pass measurement filter, at a maximum sampling time τ_0 of 1/30 seconds. The minimum measurement period for TDEV is twelve times the integration period ($T = 12\tau$).

9.1 Wander tolerance level 1

This clause defines the wander tolerance requirements for enhanced equipment clocks that are used in reference chains that are only based on ~~eEECs.~~enhanced synchronous equipment clock.

The wander tolerance requirements for an enhanced equipment clock that is part of a reference chain based on enhanced equipment clock, results in significantly lower wander accumulation in the network, as defined in clause 9.2.1.4 of [ITU-T G.8261]~~ (eEEC-based network limits) is for further study~~. An enhanced synchronous equipment clock ~~eEEC~~ implementation for such reference chains supports wander tolerance requirements according to this clause.

9.2 Wander tolerance level 2

This clause defines the wander tolerance requirements for enhanced equipment clocks that are used in reference chains that contain a mix of equipment clock [ITU-T G.8262] and enhanced equipment clock.

The wander tolerance requirements for an enhanced equipment clock that is based on a mix of enhanced equipment clocks and equipment clocks [ITU-T G.8262] in the reference chain, may result in higher wander accumulation in the network, as defined in~~ [ITU-T G.8261]~~ clause 9.2.1.1 of [ITU-T G.8261].~~ (EEC based network limits). ~~An enhanced synchronous equipment clock~~eEEC~~ implementation for such reference chains supports wander tolerance requirements according to this clause.

The input wander tolerance expressed in MTIE and TDEV limits is given in Tables 4 and 5.

Table 4 – Input wander tolerance (MTIE) for enhanced equipment clock

MTIE limit [μs]	Observation interval τ [s]
0.25	$0.1 < \tau \le 2.5$
$0.1\ \tau$	$2.5 < \tau \le 20$
2	$20 < \tau \le 400$
$0.005\ \tau$	$400 < \tau \le 1000$

Table 5 – Input wander tolerance (TDEV) for enhanced equipment clock

TDEV limit [ns]	Observation interval τ [s]
12	$0.1 < \tau \le 7$
$1.7\ \tau$	$7 < \tau \le 100$
170	$100 < \tau \le 1000$

The resultant requirements are shown in Figures 3 and 4.

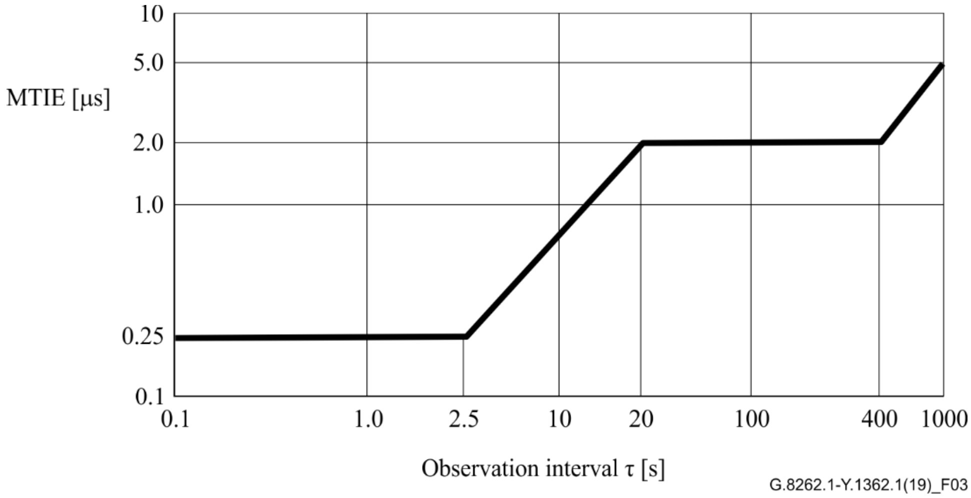


Figure 3 – Input wander tolerance (MTIE) for enhanced equipment clock

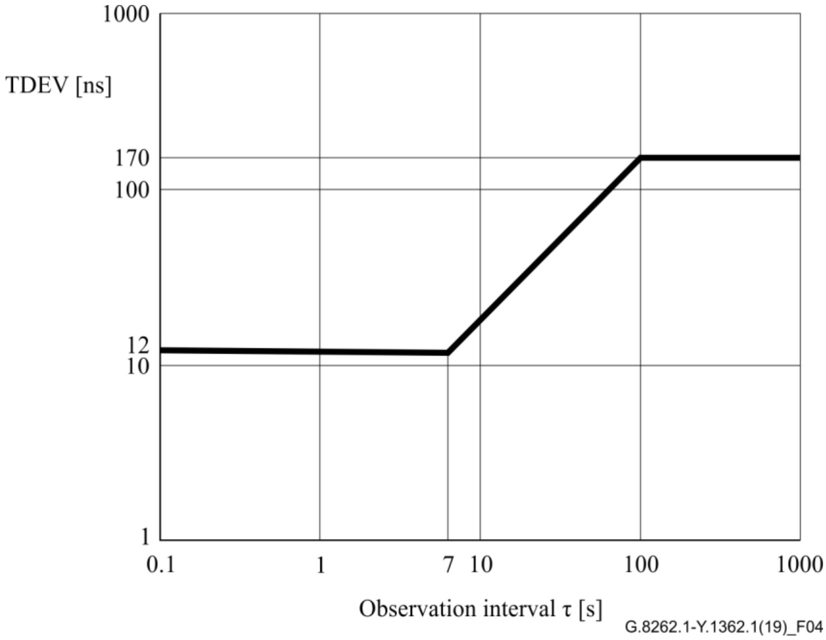


Figure 4 – Input wander tolerance (TDEV) for enhanced equipment clock

Suitable test signals that check conformance to the mask in Figure 4 are being studied. Test signals with a sinusoidal phase variation can be used, according to the levels in Table 6, to check conformance to the mask in Figure 3.

Table 6 – Lower limit of maximum tolerable sinusoidal input wander for enhanced equipment clock

Peak-to-peak wander amplitude			Wander frequency				
A_1 [µs]	A_2 [µs]	A_3 [µs]	f_4 [mHz]	f_3 [mHz]	f_2 [mHz]	f_1 [Hz]	f_0 [Hz]
0.25	2	5	0.32	0.8	16	0.13	10

The resultant requirements are shown in Figure 5.

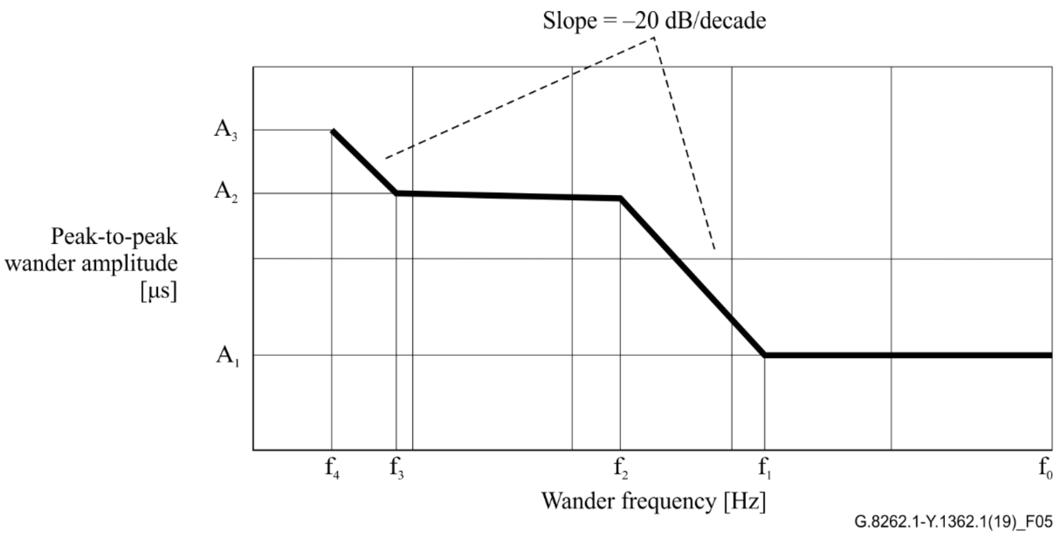


Figure 5 – Lower limit of maximum tolerable sinusoidal input wander for enhanced equipment clock 1

9.3 Jitter tolerance

This clause defines the jitter tolerance for eEEC and the eOEC.

9.3.1 Jitter tolerance for eEEC

Jitter tolerance at a synchronous Ethernet interface:

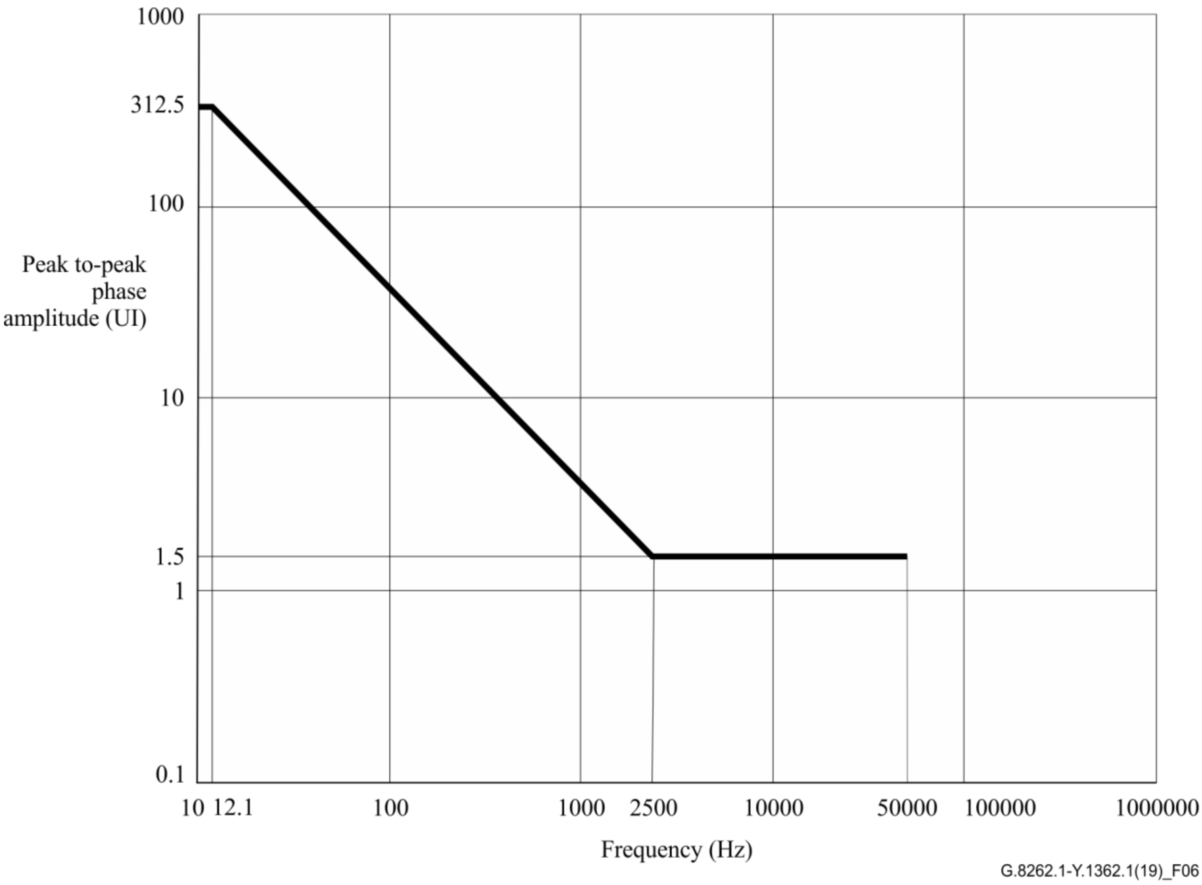
The lower limit of maximum tolerable input jitter for 1G Ethernet interfaces for eEEC is defined in clause 9.2.1 of [ITU-T G.8262].

A reference chain based solely on enhanced equipment clocks will result in lower jitter accumulation due to the lower maximum bandwidth of 3 Hz and lower noise generation of the eEEC.

The wideband jitter tolerance for 10G and 25G interfaces is for further study. ~~Option 1 is given in Table 7 and Figure 6.~~

~~Table 7 – 1G synchronous Ethernet wideband jitter tolerance for eEEC~~

~~Peak-peak jitter amplitude (UI)~~	~~Frequency f (Hz)~~
~~312.5~~	~~10 < f ≤ 12.1~~
~~3750 f^{-1}~~	~~12.1 < f ≤ 2.5 k~~
~~1.5~~	~~2.5 k < f ≤ 50 k~~
~~NOTE – 1G includes 1000BASE-KX, -SX, -LX; multi-lane interfaces are for further study.~~	



~~Figure 6 – 1G synchronous Ethernet wideband jitter tolerance for eEEC~~

~~NOTE 1 – The relevant IEEE 802.3 jitter tolerance requirements shall be met in addition to the specific synchronous Ethernet wideband jitter tolerance requirements.~~

~~NOTE 2 – For testing purposes, high frequency jitter tolerance and test signal generation for Ethernet traffic interfaces above 637 kHz are specified by [IEEE 802.3].~~

~~NOTE 3 – The slope above 50 kHz is 20 dB/decade. The actual values between 50 kHz and 637 kHz are for further study as the measurement methods between [IEEE 802.3] and ITU-T are not fully comparable. Information on the ITU jitter specification can be found in Appendix I of [ITU-T G.825].~~

~~The wideband jitter tolerance for 10G and 25G interfaces is for further study.~~

9.3.2 Jitter tolerance at 2048 kHz, 2048 kbit/s, 1544 kbit/s and STM-N interfaces

The lower limit of maximum tolerable input jitter for 2048 kHz and 2048 kbit/s signals is defined for Option 1 in clause 8.2 of [ITU-T G.813].

The lower limit of maximum tolerable jitter for external 1544 kbit/s synchronization is defined for Option 2 in clause 8.2 of [ITU-T G.813].

The lower limit of maximum tolerable input jitter for STM-N interfaces is defined in [ITU-T G.825].

9.3.3 Jitter tolerance for eOEC

Jitter tolerance for the enhanced synchronous OTN interface is defined in clause 7.1 of [ITU-T G.8251].

10 Noise transfer

The transfer characteristic of the enhanced equipment clock determines its properties with regard to the transfer of excursions of the input phase relative to the carrier phase. The enhanced equipment clock can be viewed as a low-pass filter for the differences between the actual input phase and the ideal input phase of the reference. The minimum and maximum allowed bandwidths for this low-pass filter behaviour are based on the considerations described in Appendix II of [ITU-T G.813] and are indicated below.

In the passband, the phase gain of the enhanced equipment clock should be smaller than 0.2 dB (2.3%). The above applies to a linear enhanced equipment clock model. However, this model should not restrict implementation.

The minimum bandwidth requirement for an enhanced equipment clock is 1 Hz. The maximum bandwidth requirement for an enhanced equipment clock is 3 Hz.

11 Transient response and holdover performance

The requirements in this clause apply to situations where the input signal is affected by disturbances or transmission failures (e.g., short interruptions, switching between different synchronization signals, loss of reference, etc.) that result in phase transients at the enhanced equipment clock output. The ability to withstand disturbances is necessary to avoid transmission defects or failures. Transmission failures and disturbances are common stress conditions in the transmission environment.

For short-term interruptions on synchronization input signals that do not cause reference switching, the output phase variation is for further study.

Phase discontinuity is for further study.

It is recommended that all the phase movements at the output of the enhanced equipment clock stay within the levels described in the following subclauses.

11.1 Short-term phase transient response

This requirement reflects the performance of the clock in cases when the (selected) input reference is lost due to a failure in the reference path and a second reference input signal, traceable to the same reference clock, is available simultaneously, or shortly after the detection of the failure (e.g., in cases of autonomous restoration). In such cases, the reference is lost for at most *S* seconds, where ~~the value of~~ *S* = 15 ~~is for further study~~. The output phase variation, relative to the input reference before it was lost, is bounded by the following requirements:

If the new input reference (i.e., the reference being switched to) is not an OTN reference, then the phase error should not exceed the function φ(*t*), which is given by

$$\varphi(t) = 2c + 1\times10^{-8}t \qquad 0 \le t \le S$$

If the new input reference (i.e., the reference being switched to) is an OTN reference, then~~T~~ the phase error should not exceed the function $\varphi_T(t)$. For the case $T = 0$, $\varphi_T(t)$ is given by

$$\varphi_T(t) = 2c + 1\times10^{-8}t \qquad 0 \le t \le S$$

For the case $T > 0$, $\varphi_T(t)$ is given by

$$\varphi_T(t) = \begin{cases} c\dfrac{t}{T} & 0 \le t \le 2T \\ 2c + (1\times10^{-8})(t-2T) & 2T < t \le S \end{cases}$$

The equations for φ(*t*) and $\varphi_T(t)$ hold over any period of duration *t* up to *S* seconds, where 2*c* represents two phase jumps (each of magnitude *c*) that may occur during the transition into and out of the holdover state. For OTN ports, the~~Each~~ phase jump occurs over a time interval that is not less than *T* seconds, where the value of *T* is for further study. The value of *c* should not exceed 10 ns.

Except for OTN interfaces, ~~T~~the resultant overall requirement is summarized in Figure 6. For OTN interfaces, the resultant overall requirements are summarized in Figure 7. These~~is~~ figures ~~is~~ are intended to depict the worst-case phase movement attributable to an enhanced equipment clock reference clock switch. Clocks may change state more quickly than is shown here, as long as the phase movement is below the phase movement shown in Figures 6 and 7.

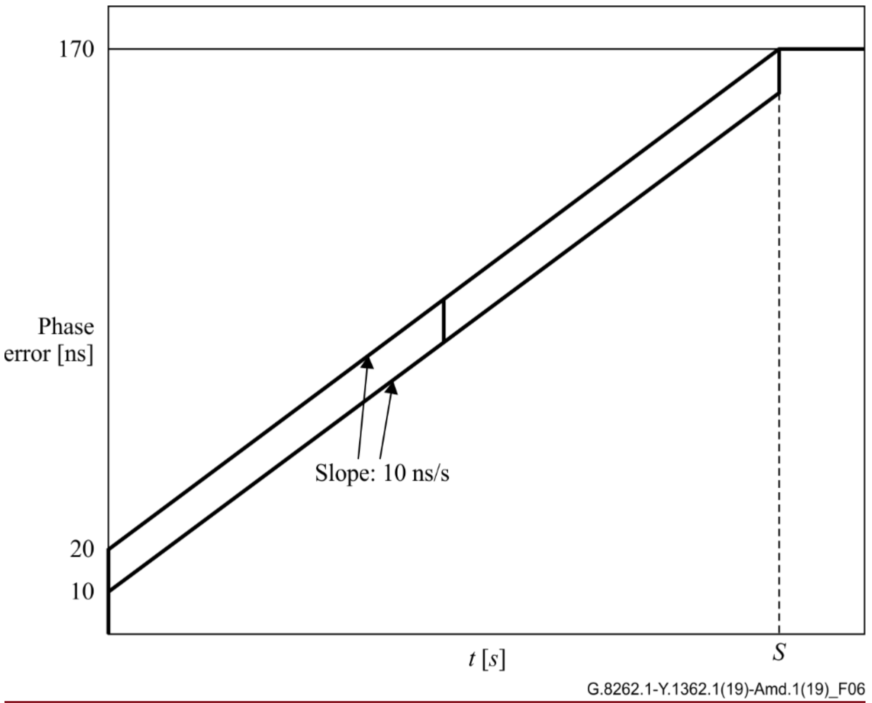


Figure 6 – Maximum phase transient at the output of the enhanced equipment clock due to reference switching (except for OTN interfaces)

Figure 6 shows two phase jumps in the clock switching transient. The first jump reflects the initial response to a loss of the synchronization reference source and subsequent entry into holdover. The magnitude of this jump is 10 ns. After the phase jump, the phase movement is restricted to lie underneath the line with a slope of 1×10^{-8} (i.e., 10 ns/s). The second phase jump, which is to take place within S seconds after entering holdover, accounts for the switching to the secondary reference. The same requirements are applicable for this jump.

An example is given in Appendix V.

NOTE 1 – Except for OTN interfaces, there is no explicit requirement on the duration of the phase jumps, i.e., the phase jumps are allowed to be instantaneous or not instantaneous. However, the phase jumps may be filtered by the clock. When the phase jumps are filtered, with filter bandwidth required to be in the range 1 – 3 Hz, the phase jumps will not be instantaneous in practice.

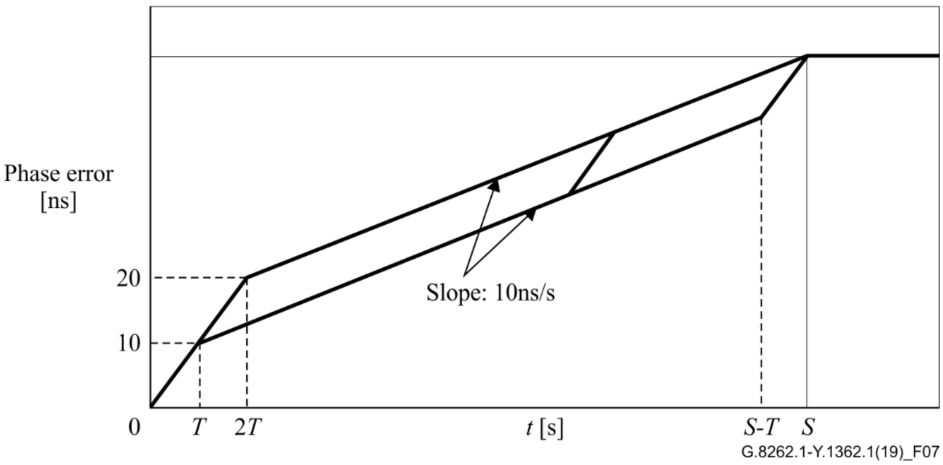


Figure 7 – Maximum phase transient at the output of the enhanced equipment clock due to reference switching (for OTN interfaces)

Figure 7 shows two phase jumps in the clock switching transient for the case where the new reference is an OTN reference. The first jump reflects the initial response to a loss of the synchronization reference source and subsequent entry into holdover. The magnitude of this jump is 10 ns over *T* seconds. After *T* seconds, the phase movement is restricted to lie underneath the line with a slope of 1×10^{-8} (i.e., 10 ns/s). The second phase jump, which is to take place within *S* seconds after entering holdover, accounts for the switching to the secondary reference. The same requirements are applicable for this jump.

NOTE ~~1~~2 – The output phase excursion, when switching between references that are not traceable to the same primary reference clock (PRC), enhanced primary reference clock (ePRC) or enhanced primary reference time clock (ePRTC), is for further study.

In cases where the input synchronization signal is lost for more than *S* seconds, the requirements in clause 11.2 apply.

NOTE ~~2~~3 – Care should be taken to accurately measure the phase transient response, as the allowed noise generation of the equipment clock is of the same order of magnitude (in terms of phase movement) as the phase jump magnitude (i.e., 10 ns). One method for the measurement of the phase transient response would be as follows. The noise generation must be measured first. The phase transient is then measured, and the total measured response should be less than the sum of the peak-to-peak noise generation over a 0.1 s observation window plus 10 ns. As an example, if the noise generation of the equipment were 5 ns over a 0.1s observation window, then the total measured response should be less than 15 ns over a 0.1s observation window at the start of the transient.

11.2 Long-term phase transient response (holdover)

This requirement bounds the maximum excursions in the output timing signal. Additionally, it restricts the accumulation of the phase movement during input signal impairments or internal disturbances.

When an enhanced equipment clock loses all its references, it enters the holdover state. The phase error, ΔT, at the output of the enhanced equipment clock relative to the input at the moment of loss of reference should, over any period $t > S$, meet the following:

$$\left|\Delta T(t)\right| \le \left\{(a_1 + a_2)t + 0.5bt^2 + c\right\} \qquad \text{[ns]}$$

where:

a_1 = 10 ns/s (see Note 1)

a_2 = 300 ns/s~~for further study~~ (see Note 2)

b = 1.16×10^{-4} ns/s^2 (see Note 3)

c = 10 ns (see Note 4)

This limit is subject to a maximum frequency offset of ±4.6 ppm. The behaviour for time intervals, t, less than or equal to S is defined in clause 11.1.

NOTE 1 – The frequency offset a_1 represents an initial frequency offset corresponding to 10 ns/s.

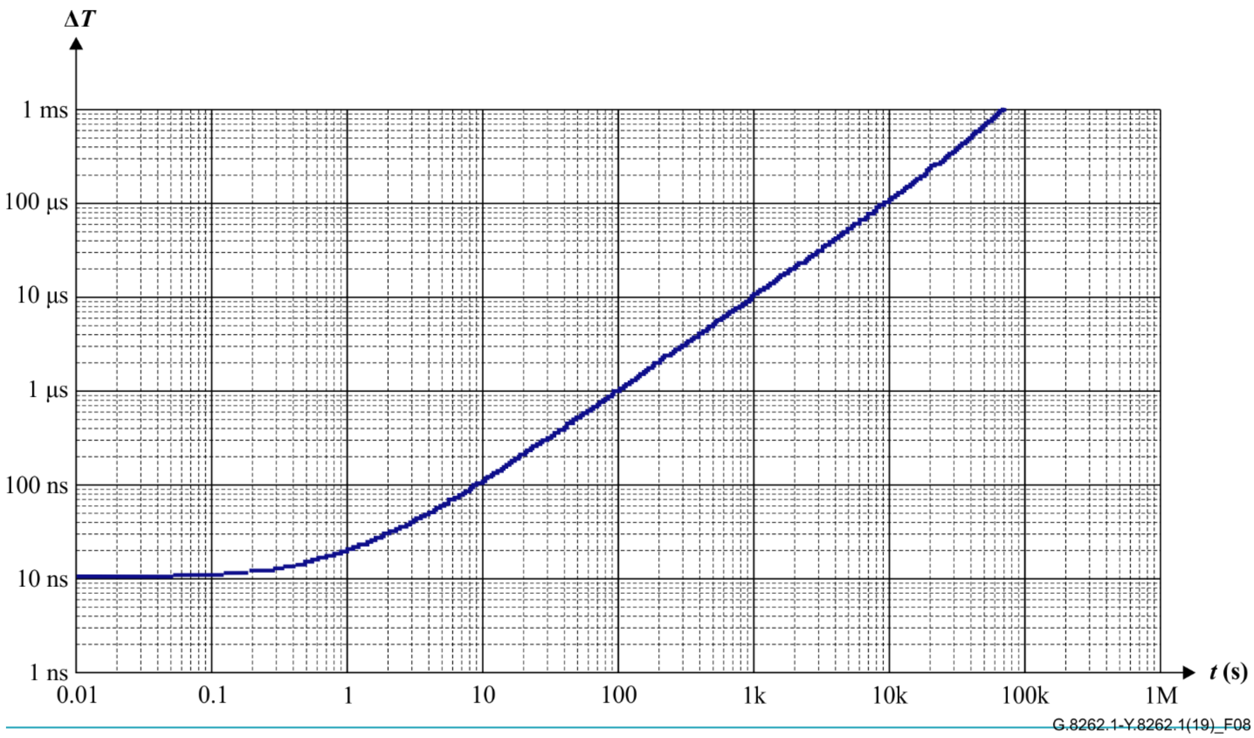
NOTE 2 – The frequency offset a_2 accounts for temperature variations after the clock went into holdover~~ and it is for further study~~. If there are no temperature variations, the term a_2t should not contribute to the phase error.

NOTE 3 – The drift b is caused by ageing: 1.16×10^{-4} ns/s^2 corresponds to a frequency drift of 1×10^{-8}/day (0.01 ppm/day). This value is derived from typical ageing characteristics after ten days of continuous operation. It is not intended to measure this value on a per day basis, as the temperature effect will dominate.

NOTE 4 – The phase offset c takes care of any additional phase shift that may arise during the transition at the entry of the holdover state.

The resultant overall requirement for constant temperature (i.e., when the temperature effect is negligible) is summarized in Figure 8.

$$\left|\Delta T(t)\right| \le \left(a_1 t + \frac{b}{2}t^2 + c\right) \qquad [ns]$$



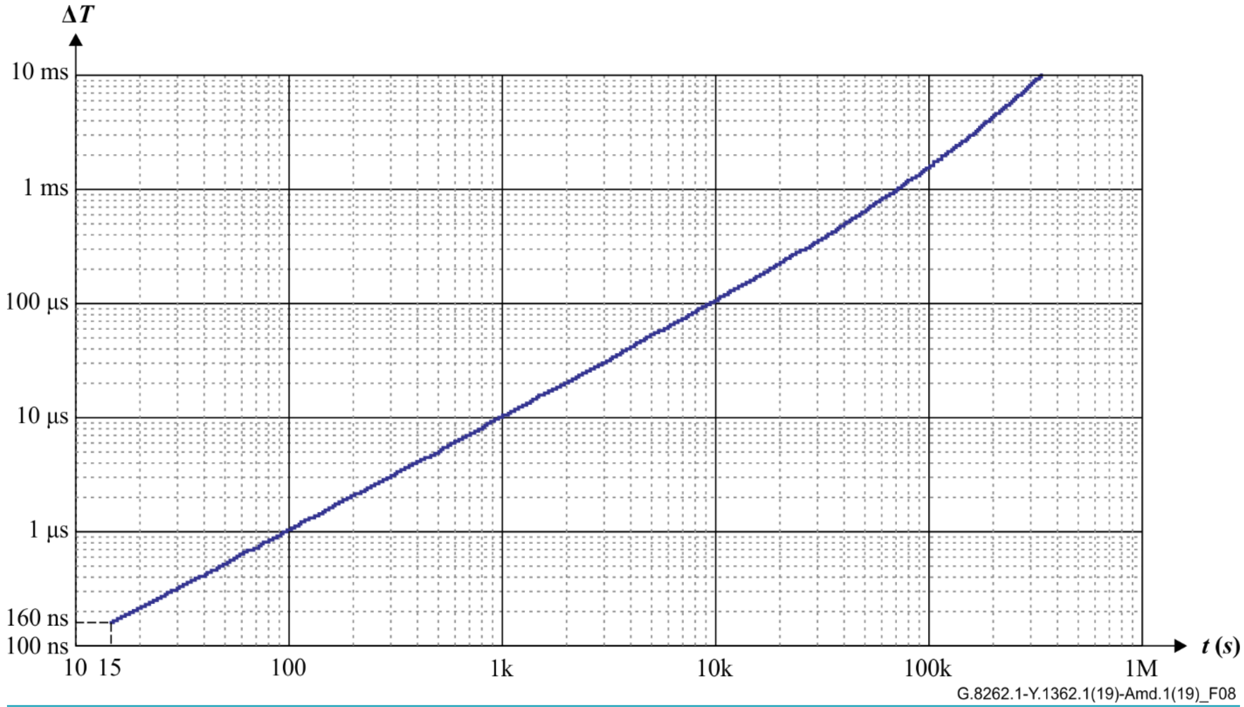


Figure 8 – Permissible phase error for an enhanced equipment clock under holdover operation at constant temperature

12 Interfaces

The requirements in this Recommendation are related to reference points internal to the network elements (NEs) in which the clock is embedded and are, therefore, not necessarily available for measurement or analysis by the user. Therefore, the performance of the enhanced equipment clock is not defined at these internal reference points, but rather at the external interfaces of the equipment.

The synchronization input and output interfaces for Ethernet equipment in which the enhanced equipment clock may be contained are:

– 1544 kbit/s interfaces according to [ITU-T G.703];
– 2048 kHz external interfaces according to [ITU-T G.703];
– 2048 kbit/s interfaces according to [ITU-T G.703];
– STM-N traffic interfaces (for hybrid NEs);
– 64 kHz interface according to [ITU-T G.703];
– 6312 kHz external interfaces according to [ITU-T G.703];
– Synchronous Ethernet interfaces;~~.~~
– Synchronous OTN interfaces.

All of the above interfaces may not be implemented on all equipment. These interfaces should comply with the jitter and wander requirements as defined in this Recommendation.

Ethernet copper interfaces allow half-duplex mode and collisions on a line which could squelch the signals and destroy the timing, therefore synchronous Ethernet interfaces must work only in full-duplex and have a continuous bit stream.

NOTE – To support interoperability with existing network equipment, interfaces to and from external network clocks may optionally support SSM.

Appendix I

Relationship between requirements contained in this Recommendation and other key synchronization-related Recommendations

(This appendix does not form an integral part of this Recommendation.)

This appendix describes the relationship between the clock performance requirements contained within the body of this Recommendation and the key synchronization Recommendations that are under development, or have been developed within Question 13 (Network synchronization and time distribution performance) of ITU-T Study Group 15.

This Recommendation describes performance requirements for enhanced synchronous equipment clocks. This Recommendation addresses enhanced synchronous Ethernet and enhanced synchronous OTN clocks.

The basic concept of synchronous Ethernet is described in [ITU-T G.8261], the first ITU-T Recommendation to detail network synchronization aspects applicable to packet-based networks.

If a clock described in this Recommendation is embedded in an Ethernet network element, it allows transfer of network traceable timing via the Ethernet physical layer. In this context, the Ethernet physical layer is defined by [IEEE 802.3]. If a clock described in this Recommendation is embedded in an OTN network element, it allows transfer of network traceable timing via the OTN physical layer. In this context, the OTN physical layer is defined by [ITU-T G.709].

The enhanced equipment clocks may be consistent with existing SDH network element clocks used in the distribution of frequency. In this case, synchronization network engineering will not require any change to current network engineering practices.

Synchronization networks in general are based on SDH synchronization distribution as described in [ITU-T G.803]. Synchronization distribution may follow specific regional practices in order to meet the fundamental performance requirements and network interface limits from either [b-ITU-T G.823] or [b-ITU-T G.824] for the 2048 kbit/s or 1544 kbit/s hierarchy, respectively. Both [b-ITU-T G.823] and [b-ITU-T G.824] are based on the fundamental slip rate objectives in [b-ITU-T G.822].

The equipment clocks are purposely specified to perform in a manner consistent with existing synchronization networks. They can be deployed within the synchronization distribution network in exactly the same manner as an ITU-T G.813 SEC.

Appendix II

List of Ethernet interfaces applicable to synchronous Ethernet

(This appendix does not form an integral part of this Recommendation.)

The list of Ethernet interfaces applicable to synchronous Ethernet can be found in Appendix III of [ITU-T G.8262].

Appendix III

Considerations related to synchronous Ethernet over 1000BASE-T and 10GBASE-T

(This appendix does not form an integral part of this Recommendation.)

Considerations related to synchronous Ethernet over 1000BASE-Ta and 10GBASE-T can be found in Appendix IV of [ITU-T G.8262].

Appendix IV

Performance estimation for cascaded media converters acting as enhanced synchronous equipment clocks

(This appendix does not form an integral part of this Recommendation.)

~~This appendix is intended to define cascaded media converters acting as enhanced clock performance estimation. This is for further study.~~

On some specific media interfaces (e.g., OSC in case of OTN), test equipment may not be available to measure all aspects of the equipment clock performance. For such cases, this appendix describes a back-to-back measurement methodology as shown in Figure IV.1. This appendix also describes how to estimate the performance budget to use for back-to-back equipment clock in Figure IV.1, where each media converter equipment clock is allocated the budget equivalent to a single enhanced synchronous equipment slave clock in the body of this Recommendation.

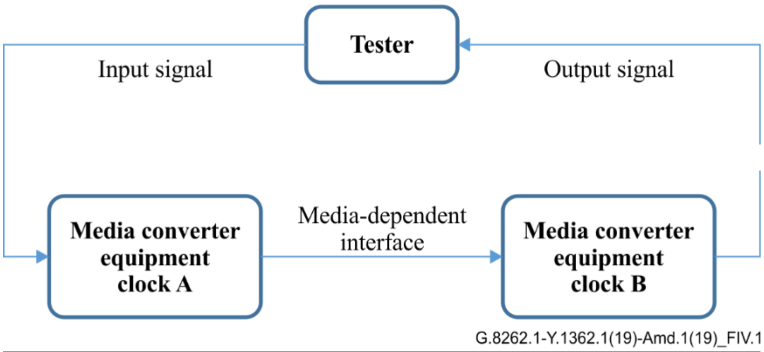


Figure IV.1 – Measurement for testing media converter equipment clocks

NOTE – The performance estimation below can be used for the back-to-back equipment clocks with OTN technology between two media converter equipment clocks, and the performance estimation of back-to-back media converter equipment clocks with other technologies are for further study.

IV.1 Noise generation

The wander generation expected at the output of the media converter equipment clock B can be estimated as the wander generation of a single eSEC multiplied by the square root of two. Note that the wander generation of the media converter equipment clock A could be directly verified in isolation via its other interfaces, i.e., 2048 kHz, 2048 kbit/s or Ethernet.

The jitter generation expected at the output of the media converter equipment clock B can be estimated to be the same as the jitter generation of a single eSEC.

IV.2 Noise tolerance

As the noise tolerance at the input to media converter equipment clock B cannot be tested directly on the interface between the media converter equipment clocks, the test can be done at the input to the media converter equipment clock A using one of its other interfaces, i.e., 2048 kHz, 2048 kbit/s or Ethernet. The noise tolerance at the input of the media converter equipment clock A is estimated to be the same as the noise tolerance of a single eSEC.

IV.3 Noise transfer

The noise transfer performance estimation for back-to-back equipment clocks is as follows:

The noise transfer of the output of the cascaded media converter equipment clocks would have:

– A maximum gain of 0.4 dB,

– A maximum bandwidth of 3 Hz,

– A minimum gain of −6 dB for frequencies less than or equal to 1 Hz.

NOTE 1 – The minimum bandwidth specified for one eSEC is 1 Hz. If two clocks whose 3 dB bandwidths are 1 Hz are cascaded, the overall gain of the cascaded clocks taken together is −6 dB for frequencies less than or equal to 1 Hz. The 3 dB bandwidth of the cascaded clocks taken together is less than 1 Hz.

NOTE 2 – This clause does not add or modify requirements contained in the normative parts of this Recommendation.

NOTE 3 – The noise transfer test of one single media converter equipment clock could be done in isolation via its other interfaces, i.e., 2048 kHz, 2048 kbit/s or Ethernet.

IV.4 Transient response and holdover performance

The phase transient response and holdover performance of the output of the media converter equipment clock B, including short-term phase transient, long-term phase transient, phase response to input signal interruptions and phase discontinuity, can be estimated to be the same as the transient response and holdover performance of a single eSEC. The signal interruption to initiate this test can be done at the link between two media converter equipment clocks A and B, or at the input to the equipment clock A via its other interfaces, i.e., 2048 kHz, 2048 kbit/s or Ethernet. When the signal interruption is introduced on clock A to conduct this test, clock B must be kept locked to the input from clock A in order to measure the resulting transient.

Appendix V

Example for short-term phase transient response

(This appendix does not form an integral part of this Recommendation.)

The short-term phase transient response requirement reflects the performance of the clock in cases when the input reference is lost and a second reference input signal, traceable to the same reference clock, is available simultaneously, or shortly after the detection of the failure (i.e., within S seconds).

This appendix gives an example for a better understanding of the short-term phase transient response requirements given in clause 11.1.

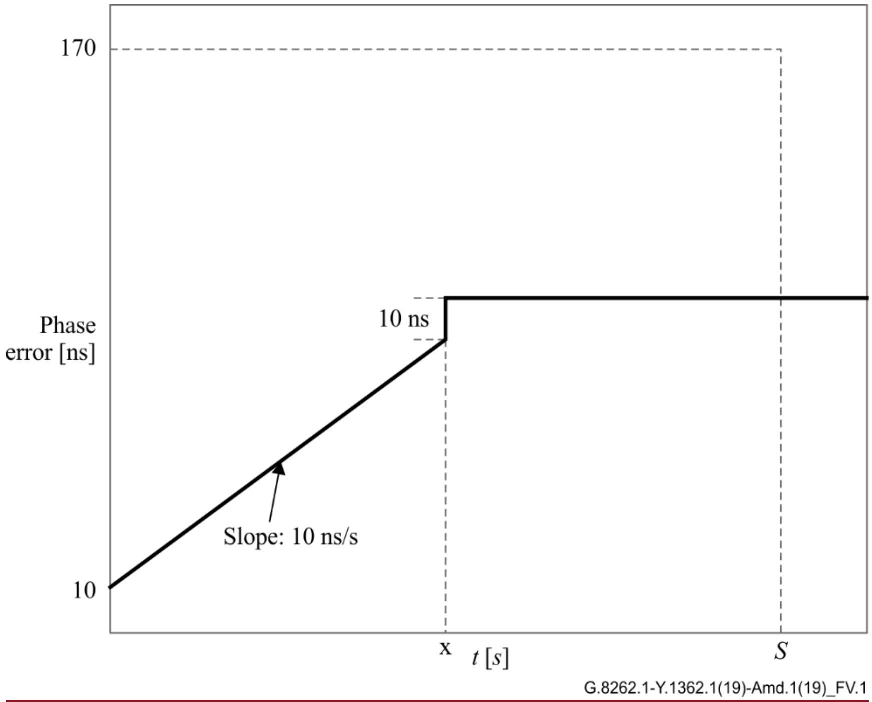


Figure V.1 – Example of phase transient at the output of the enhanced equipment clock due to reference switching (except for OTN interfaces)

When the active/selected input reference is lost, the enhanced equipment clock enters the holdover state. Associated with this action, a first jump with a maximum magnitude of 10 ns is allowed as shown at the left side of the mask in Figure V.1. In the holdover state, the phase movement is restricted to lie underneath the line with a slope of 1×10^{-8} s/s (i.e., 10 ns/s). When a second reference input signal is available and qualified, the enhanced equipment clock switches to the second reference. Associated with this action, the second jump with a maximum magnitude of 10 ns is allowed, as shown in Figure V.1, at x seconds ($0 < x \leq S$). This leads to a total phase error of $\varphi(t) = 2c + 1 \times 10^{-8} t$, (c=10 ns, at t=x).

Bibliography

[b-ITU-T G.783] Recommendation ITU-T G.783 (2006), *Characteristics of synchronous digital hierarchy (SDH) equipment functional blocks*.

[b-ITU-T G.801] Recommendation ITU-T G.801 (1988), *Digital transmission models*.

[b-ITU-T G.822] Recommendation ITU-T G.822 (1988), *Controlled slip rate objectives on an international digital connection*.

[b-ITU-T G.823] Recommendation ITU-T G.823 (2000), *The control of jitter and wander within digital networks which are based on the 2048 kbit/s hierarchy*.

[b-ITU-T G.824] Recommendation ITU-T G.824 (2000), *The control of jitter and wander within digital networks which are based on the 1544 kbit/s hierarchy*.

[b-ITU-T G.8010] Recommendation ITU-T G.8010/Y.1306 (2004), *Architecture of Ethernet layer networks*.

[b-ITU-T O.174] Recommendation ITU-T O.174 (2009), *Jitter and wander measuring equipment for digital systems which are based on synchronous Ethernet technology*.

[b-ITU-T Q.551] Recommendation ITU-T Q.551 (2002), *Transmission characteristics of digital exchanges*.

ITU-T Y-SERIES RECOMMENDATIONS

GLOBAL INFORMATION INFRASTRUCTURE, INTERNET PROTOCOL ASPECTS, NEXT-GENERATION NETWORKS, INTERNET OF THINGS AND SMART CITIES

GLOBAL INFORMATION INFRASTRUCTURE	
General	Y.100–Y.199
Services, applications and middleware	Y.200–Y.299
Network aspects	Y.300–Y.399
Interfaces and protocols	Y.400–Y.499
Numbering, addressing and naming	Y.500–Y.599
Operation, administration and maintenance	Y.600–Y.699
Security	Y.700–Y.799
Performances	Y.800–Y.899
INTERNET PROTOCOL ASPECTS	
General	Y.1000–Y.1099
Services and applications	Y.1100–Y.1199
Architecture, access, network capabilities and resource management	Y.1200–Y.1299
Transport	**Y.1300–Y.1399**
Interworking	Y.1400–Y.1499
Quality of service and network performance	Y.1500–Y.1599
Signalling	Y.1600–Y.1699
Operation, administration and maintenance	Y.1700–Y.1799
Charging	Y.1800–Y.1899
IPTV over NGN	Y.1900–Y.1999
NEXT GENERATION NETWORKS	
Frameworks and functional architecture models	Y.2000–Y.2099
Quality of Service and performance	Y.2100–Y.2199
Service aspects: Service capabilities and service architecture	Y.2200–Y.2249
Service aspects: Interoperability of services and networks in NGN	Y.2250–Y.2299
Enhancements to NGN	Y.2300–Y.2399
Network management	Y.2400–Y.2499
Network control architectures and protocols	Y.2500–Y.2599
Packet-based Networks	Y.2600–Y.2699
Security	Y.2700–Y.2799
Generalized mobility	Y.2800–Y.2899
Carrier grade open environment	Y.2900–Y.2999
FUTURE NETWORKS	Y.3000–Y.3499
CLOUD COMPUTING	Y.3500–Y.3999
INTERNET OF THINGS AND SMART CITIES AND COMMUNITIES	
General	Y.4000–Y.4049
Definitions and terminologies	Y.4050–Y.4099
Requirements and use cases	Y.4100–Y.4249
Infrastructure, connectivity and networks	Y.4250–Y.4399
Frameworks, architectures and protocols	Y.4400–Y.4549
Services, applications, computation and data processing	Y.4550–Y.4699
Management, control and performance	Y.4700–Y.4799
Identification and security	Y.4800–Y.4899
Evaluation and assessment	Y.4900–Y.4999

For further details, please refer to the list of ITU-T Recommendations.

SERIES OF ITU-T RECOMMENDATIONS

Series A	Organization of the work of ITU-T
Series D	Tariff and accounting principles and international telecommunication/ICT economic and policy issues
Series E	Overall network operation, telephone service, service operation and human factors
Series F	Non-telephone telecommunication services
Series G	**Transmission systems and media, digital systems and networks**
Series H	Audiovisual and multimedia systems
Series I	Integrated services digital network
Series J	Cable networks and transmission of television, sound programme and other multimedia signals
Series K	Protection against interference
Series L	Environment and ICTs, climate change, e-waste, energy efficiency; construction, installation and protection of cables and other elements of outside plant
Series M	Telecommunication management, including TMN and network maintenance
Series N	Maintenance: international sound programme and television transmission circuits
Series O	Specifications of measuring equipment
Series P	Telephone transmission quality, telephone installations, local line networks
Series Q	Switching and signalling, and associated measurements and tests
Series R	Telegraph transmission
Series S	Telegraph services terminal equipment
Series T	Terminals for telematic services
Series U	Telegraph switching
Series V	Data communication over the telephone network
Series X	Data networks, open system communications and security
Series Y	**Global information infrastructure, Internet protocol aspects, next-generation networks, Internet of Things and smart cities**
Series Z	Languages and general software aspects for telecommunication systems

Printed in Switzerland
Geneva, 2019