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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 telecom transparent clocks for use with full timing support from the network

Recommendation ITU-T G.8273.3/Y.1368.3

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Recommendation ITU-T G.8273.3/Y.1368.3

Timing characteristics of telecom transparent clocks for use with full timing support from the network

Summary

Recommendation ITU-T G.8273.3/Y.1368.3 defines the minimum requirements for telecom transparent clocks (T-TCs). These requirements apply under normal environmental conditions specified for the equipment.

This Recommendation includes: clock accuracy, noise generation, noise tolerance, noise transfer, and transient response for T-TCs.

History

Edition	Recommendation	Approval	Study Group	Unique ID*
1.0	ITU-T G.8273.3/Y.1368.3	2017-10-07	15	11.1002/1000/13327
1.1	ITU-T G.8273.3/Y.1368.3 (2017) Amd. 1	2018-11-29	15	11.1002/1000/13770
2.0	ITU-T G.8273.3/Y.1368.3	2020-10-29	15	11.1002/1000/14508

Keywords

PTP, phase and time synchronization, telecom profile, transparent clock.

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* 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

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Table of Contents

Recommendation ITU-T G.8273.3/Y.1368.3

Timing characteristics of telecom transparent clocks for use with full timing support from the network

1 Scope

This Recommendation specifies minimum requirements for time and phase synchronization devices used in synchronizing network equipment, which operates in the network architecture as defined in [ITU-T G.8271] and [ITU-T G.8275]. It supports time and/or phase synchronization distribution for packet-based networks. The telecom transparent clock (T-TC) must be operating in end-to-end transparent clock (TC) mode.

This Recommendation assumes operation within the framework specified in [ITU-T G.8273], and that the physical layer reference chain behaviors given in [ITU-T G.803] and [ITU-T G.8261] are followed. It is also assumed that the network limits given in [ITU-T G.8271.1] are met and that the profile given in [ITU-T G.8275.1] is applied.

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

This Recommendation defines the minimum requirements for transparent clocks. These requirements apply under normal environmental conditions specified for the equipment.

Guidelines for testing are described in Appendix I.

For T-TC classes A and B, this version of the Recommendation focuses on syntonized T-TCs with frequency reference provided by the physical layer based on [ITU-T G.8262] Option 1 (and [ITU-T G.813] Option 1 as the requirements are identical). [ITU-T G.8262] Option 2 and [ITU-T G.813] Option 2 are for further study. A T-TC without a frequency reference provided by the physical layer is for further study. [ITU-T G.8262.1] is a higher accuracy clock compared to [ITU-T G.8262], therefore it can also be used for T-TC classes A and B.

For T-TC class C, this version of the Recommendation focuses on syntonized T-TCs with frequency reference provided by the physical layer based on [ITU-T G.8262.1].

NOTE 1 – This Recommendation does not modify the physical layer reference chain behaviour, according to [ITU-T G.803] and [ITU-T G.8261]. This Recommendation does not exclude the use of other physical layer clocks (e.g., [ITU-T G.812] Type I) within the frequency transport network. The equipment specification of a T-TC assisted by a physical layer equipment clock, other than [ITU-T G.8262] Option 1 and [ITU-T G.8262.1], such as [ITU-T G.812] Type I, is for further study.

NOTE 2 – This version of the Recommendation was developed based on the hypothetical reference model (HRM) defined in clause II.2 of [ITU-T G.8271.1]. The use of T-TCs for more stringent network limits than that of accuracy level 4 in Table 1 of [ITU-T G.8271] is for further study.

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 (2016), *Physical/electrical characteristics of hierarchical digital interfaces*.

[ITU-T G.781] Recommendation ITU-T G.781 (2020), *Synchronization layer functions for frequency synchronization based on the physical layer*.

[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.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.8260] Recommendation ITU-T G.8260 (2020), *Definitions and terminology for synchronization in packet networks*.

[ITU-T G.8261] Recommendation ITU-T G.8261/Y.1361 (2019), *Timing and synchronization aspects in packet networks*.

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

[ITU-T G.8262.1] Recommendation ITU-T G.8262.1/Y.1362.1 (2019), *Timing characteristics of an enhanced synchronous 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.8271] Recommendation ITU-T G.8271/Y.1366 (2020), *Time and phase synchronization aspects of telecommunication networks*.

[ITU-T G.8271.1] Recommendation ITU-T G.8271.1/Y.1366.1 (2020), *Network limits for time synchronization in packet networks with full timing support from the network*.

[ITU-T G.8273] Recommendation ITU-T G.8273/Y.1368 (2018), *Framework of phase and time clocks*.

[ITU-T G.8275] Recommendation ITU-T G.8275/Y.1369 (2020), *Architecture and requirements for packet-based time and phase distribution*.

[ITU-T G.8275.1] Recommendation ITU-T G.8275.1/Y.1369.1 (2020), *Precision time protocol telecom profile for phase/time synchronization with full timing support from the network*.

3 Definitions

3.1 Terms defined elsewhere

Definitions related to synchronization are contained in [ITU-T G.810] and [ITU-T G.8260].

3.2 Terms defined in this Recommendation

None.

4 Abbreviations and acronyms

This Recommendation uses the following abbreviations and acronyms:

cTE Constant phase/Time Error

dTE Dynamic Time Error

EEC	synchronous Ethernet Equipment Clock
ESMC	Ethernet Synchronization Messaging Channel
GbE	Gigabit Ethernet
HRM	Hypothetical Reference Model
max|TE|	Maximum absolute Time Error
MTIE	Maximum Time Interval Error
NE	Network Element
PEC	Packet-based Equipment Clock
PP	Packet Processing
PPS	Pulse Per Second
PRTC	Primary Reference Time Clock
PTP	Precision Time Protocol
SDH	Synchronous Digital Hierarchy
SEC	Synchronous Equipment Clock
SSM	Synchronization Status Message
SyncE	Synchronous Ethernet
T-GM	Telecom Grandmaster
T-TSC	Telecom Time Slave Clock
T-TC	Telecom Transparent Clock
TDEV	Time Deviation
TE	Time Error

5 Conventions

None.

6 Physical layer frequency performance requirements

The list of applicable physical layer frequency interfaces is provided in clause 8.2.

6.1 Synchronous equipment clock interfaces

Synchronous equipment clock interfaces used in combination with the telecom transparent clock (T-TC) are specified in [ITU-T G.8262] and generate and process Ethernet synchronization messaging channel (ESMC) messages as specified in [ITU-T G.8264].

Synchronous digital hierarchy (SDH) interfaces and SDH equipment slave clocks used in combination with the T-TC are specified in [ITU-T G.813], and generate and process synchronization status message (SSM) messages as specified in [ITU-T G.781].

NOTE – The T-TC model in this Recommendation does not exclude the use of other physical layer clocks (e.g., ITU-T G.812 Type I) within the equipment related to the operation between the physical layer input to physical layer output interface behaviour, in accordance with the existing [ITU-T G.803] reference chain and [ITU-T G.8261] network limits. In such cases, the equipment behaviour related to the interaction between the physical layer input and the precision time protocol (PTP) output is for further study.

6.2 Enhanced synchronous equipment clock interfaces

Enhanced synchronous equipment clocks used in combination with the telecom transparent clock (T-TC) are specified in [ITU-T G.8262.1] and generate and process Ethernet synchronization messaging channel (ESMC) messages as specified in [ITU-T G.8264].

Enhanced synchronous equipment clock can be used in combination with all the T-TC classes. To achieve the required performance of T-TC class C, such T-TC can only be used in combination with enhanced synchronous equipment clock as specified in [ITU-T G.8262.1].

7 Packet layer performance requirements

7.1 Constant phase/time error and dynamic time error noise generation

The noise generation of a T-TC represents the amount of noise produced at the output of the T-TC when there is an ideal input reference packet timing signal.

Under normal operating conditions, the time output of the T-TC should be accurate to within the maximum absolute time error (TE) (max|TE|). This value includes all the noise components, i.e., the constant time error (cTE) and the dynamic time error (dTE) noise generation. In order to support different performance requirements at the end application specified in Table 1 of [ITU-T G.8271] using different network topologies and network technologies, the max|TE|, cTE and dTE noise generation requirements for T-TCs are divided into three classes: class A, class B, and class C. A T-TC with physical layer support must meet the requirements stated in clauses 7.1.1, 7.1.2 and 7.1.3.

7.1.1 Maximum absolute time error generation

At the precision time protocol (PTP) output, the maximum absolute time error (max|TE|) for T-TC is shown in Table 7-1. This includes all time error components (unfiltered).

Table 7-1 – Maximum absolute time error

T-TC class	Maximum absolute time error – max|TE| (ns)
A	100
B	70
C	For further study

NOTE 1 – The values in Table 7-1 are valid for 1GbE, 10GbE, 25GbE, 40GbE and 100GbE interfaces. Values for other interfaces are for further study.

NOTE 2 – Max|TE| for T-TC class C is for further study, but it should be smaller than that for class B.

7.1.2 Constant time error generation (cTE)

At the PTP outputs, the cTE generation for class A and class B is shown in Table 7-2.

Table 7-2 – T-TC permissible range of cTE

T-TC class	Permissible range of cTE (ns)
A	±50
B	±20
C	±10

NOTE 1 – The values in Table 7-2 are valid for 1GbE, 10GbE, 25GbE, 40GbE and 100GbE interfaces. Values for other interfaces are for further study.

NOTE 2 – Constant time error and the method to estimate are defined in [ITU-T G.8260]. For the purpose of testing the limits in Table 7-2, an estimate of constant time error should be obtained by averaging the time error sequence over 1000 s.

NOTE 3 – Interfaces whose optical modules have uncontrolled asymmetric latency are for further study.

NOTE 4 – The constant time error (cTE) is measured at constant temperature (within ±1K).

7.1.3 Dynamic time error low-pass filtered noise generation (dTE_L)

The dynamic time error low-pass filtered noise generation (dTE_L) for a T-TC under constant temperature (within ±1 K) is shown in Table 7-3. A T-TC class A or class B containing an Option 1 clock, as specified in [ITU-T G.8262], or containing an enhanced synchronous equipment clock, as specified in [ITU-T G.8262.1] should meet the limits for class A or class B.

A T-TC class C containing an enhanced synchronous equipment clock, as specified in [ITU-T G.8262.1] should meet the limits for class C.

When the T-TC is operating in normal mode synchronized to both a wander-free time reference at the PTP input and a wander-free frequency reference at the physical layer frequency input, the maximum time interval error (MTIE) under constant temperature (within ±1 K) at the PTP outputs, measured through a first-order low-pass filter with bandwidth of 0.1 Hz, should meet the limits in Table 7-3.

Table 7-3 – Dynamic time error noise generation (MTIE) for T-TC with constant temperature

T-TC class	MTIE limit (ns)	Observation interval τ (s)
A	40	$m < \tau \leq 1000$ (Note 1), (Note 2)
B	40	$m < \tau \leq 1000$ (Note 1), (Note 2)
C	10	$m < \tau \leq 1000$ (Note 1), (Note 2)
NOTE 1 – The minimum τ value *m* is determined by a packet rate of 16 packet per second (*m*=1/16). NOTE 2 – The values in Table 7-3 are valid for 1GbE, 10GbE, 25GbE, 40GbE and 100GbE interfaces. Values for other interfaces are for further study.		

When temperature effects are included, the MTIE requirement is defined in Table 7-4 for a T-TC. In this case, the maximum observation interval is increased to 10000 s.

Table 7-4 – Dynamic time error noise generation (MTIE) for T-TC with variable temperature

T-TC class	MTIE limit (ns)	Observation interval τ (s)
A	40	$m < \tau \leq 10000$ (Note 1), (Note 2)
B	40	$m < \tau \leq 10000$ (Note 1), (Note 2)
C	For further study	$m < \tau \leq 10000$ (Note 1), (Note 2)
NOTE 1 – The minimum τ value *m* is determined by a packet rate of 16 packet per second (*m*=1/16). NOTE 2 – The values in Table 7-4 are valid for 1GbE, 10GbE, 25GbE, 40GbE and 100GbE interfaces. Values for other interfaces are for further study.		

NOTE – Guidelines for variable temperature testing are described in Appendix II of [ITU-T G.8273].

The applicable time deviation (TDEV) is for further study.

7.1.4 Dynamic time error high-pass filtered noise generation (dTE_H)

For a T-TC class A and class B syntonized to an Option 1 clock, as specified in [ITU-T G.8262], or to an enhanced synchronous equipment clock, as specified in [ITU-T G.8262.1], and operating in a locked mode synchronized to a noise-free frequency reference at the physical layer frequency input, and connected to a noise-free time reference at the PTP input, the peak-to-peak time error at the T-TC output interfaces, measured over a 1000 s measurement interval, with a first-order high-pass filter of 0.1 Hz must be less than 70 ns.

NOTE – The value of 70 ns is a conservative limit based on the SEC/EEC noise generation specification. This is based on the assumption that most of this noise is generated by the high-pass filtered noise of the [ITU-T G.8262] oscillator. It is expected that implementations based on better clocks can result in significantly lower values. It is not intended and not assumed that the component of the high-pass filtered noise, due to timestamp granularity, is a major portion of the 70 ns.

The dynamic time error high-pass filtered noise generation (dTE_H) is for further study for T-TC class C.

7.2 Noise tolerance

The noise tolerance of a T-TC indicates the minimum dTE level at the input of the clock that should be accommodated while:

– not causing any alarms;

– not causing the clock to switch reference;

– not causing the clock to go into holdover.

NOTE 1 – PTP noise tolerance concerns clock recovery from PTP for T-TC syntonization purposes. The current scope of this Recommendation focuses on a case of T-TC syntonized by means of physical layer frequency synchronization; the case of syntonization provided by PTP is for further study.

NOTE 2 – There is no requirement related to cTE tolerance.

NOTE 3 – dTE tolerance on the PTP input is not applicable in the case of a T-TC with physical layer frequency synchronization assistance. The current scope of this Recommendation focuses on a case of T-TC syntonized by means of physical layer frequency synchronization; the case of syntonization provided by PTP is for further study;

7.2.1 Noise tolerance for clock classes A and B

A T-TC classes A and B for use in the full timing support profile should be capable of tolerating the following levels of dTE and phase wander on the frequency layer frequency synchronization input:

– wander tolerance according to [ITU-T G.8262], clause 9.1.1 at the synchronous equipment clock input;

– wander tolerance according to [ITU-T G.813] clause 8.1 at the SDH input

7.2.2 Noise tolerance for clock class C

A T-TC class C for use in the full timing support profile should be capable of tolerating the following levels of dTE and phase wander on the frequency plane signal:

– wander tolerance according to [ITU-T G.8262.1], clause 9 at the enhanced synchronous equipment clock input;

7.3 Noise transfer

7.3.1 PTP to PTP noise transfer

There is no filtering of PTP signal required in the T-TC. The T-TC is not permitted to amplify input time error on its output.

NOTE – The current scope of this Recommendation focuses on a case of T-TC syntonized by means of physical layer frequency synchronization; the case of syntonization provided by PTP for which this specification would become relevant, is for further study.

7.3.2 Physical layer frequency to PTP noise transfer

For the case of a T-TC with physical layer frequency synchronization assistance, the noise transferred to the output PTP signal (i.e., as observable on the residence time measurements) corresponds to the input physical layer frequency input signal filtered by a low-pass filter, whose corner frequency is between 1 Hz and 10 Hz, followed by a high-pass filter, whose corner frequency depends on the residence time (i.e., inverse of twice the residence time). In particular, it can be assumed that the residence time is controlled to be less than the PTP packet rate (1/16 of a second) and is typically in the order of 10 µs – 10 ms, so that the high-pass corner frequency is between 8 Hz and 50 kHz (i.e., the Nyquist frequencies corresponding to 1/16 s and 10 µs, respectively). This means that the noise of the input physical layer frequency is generally greatly reduced.

In the passband, the phase gain of the synchronous equipment clock should be smaller than 0.2 dB (2.3%).

NOTE – For a T-TC class A and B, the above requirement applies to the case where a physical layer clock is implemented as per [ITU-T G.8262] Option 1 to assist the T-TC, where the filter bandwidth is between 1 Hz and 10 Hz. When a different physical layer clock is used with a lower filter bandwidth to assist the T-TC class A or B, such as [ITU-T G.812] Type I, the relevant filter bandwidth characteristics would apply.

NOTE 2 – For a T-TC class C, the above requirement applies to the case where a physical layer clock is implemented as per [ITU-T G.8262.1] to assist the T-TC, where the filter bandwidth is between 1 Hz and 3 Hz. The detailed characteristics of the T-TC class C based on clocks different from [ITU-T G.8262.1] is for further study.

7.4 Packet layer transient response and holdover performance

7.4.1 Transient response

7.4.1.1 PTP to PTP transient response

The PTP to PTP transient response requirements applicable to a T-TC are for further study.

7.4.1.2 Physical layer frequency to PTP transient response

For further study.

7.4.2 Holdover performance

A T-TC does not support time holdover.

8 Interfaces

The requirements in this Recommendation are related to reference points which may be internal to the equipment or network element (NE) in which the T-TC is embedded and are, therefore, not necessarily available for measurement or analysis by the user. Consequently, the performance of the T-TC is not specified at these internal reference points, but rather at the external interfaces of the equipment.

Not all of the interfaces below need to be implemented on all equipment.

8.1 Phase and time interfaces

The phase and time interfaces specified for the equipment in which the T-TC may be contained are:

– Ethernet interface carrying PTP messages;

NOTE – Ethernet interfaces can combine SyncE for frequency and PTP messages.

– other interfaces are for further study.

8.2 Frequency interfaces

The frequency interfaces specified for the equipment in which the T-TC may be contained are:

– 2048 kHz interfaces according to [ITU-T G.703] with additional jitter and wander requirements as specified herein;

– 1544 kbit/s interfaces according to [ITU-T G.703] with additional jitter and wander requirements as specified herein;

– 2048 kbit/s interfaces according to [ITU-T G.703] with additional jitter and wander requirements as specified herein;

– synchronous transport module level-N (STM-N) traffic interfaces;

– synchronous Ethernet interfaces;

NOTE – Ethernet interfaces can combine PTP and SyncE.

– other interfaces are for further study.

Annex A

Telecom transparent clock functional model

(This annex forms an integral part of this Recommendation.)

Figure A.1 illustrates a transparent clock model.

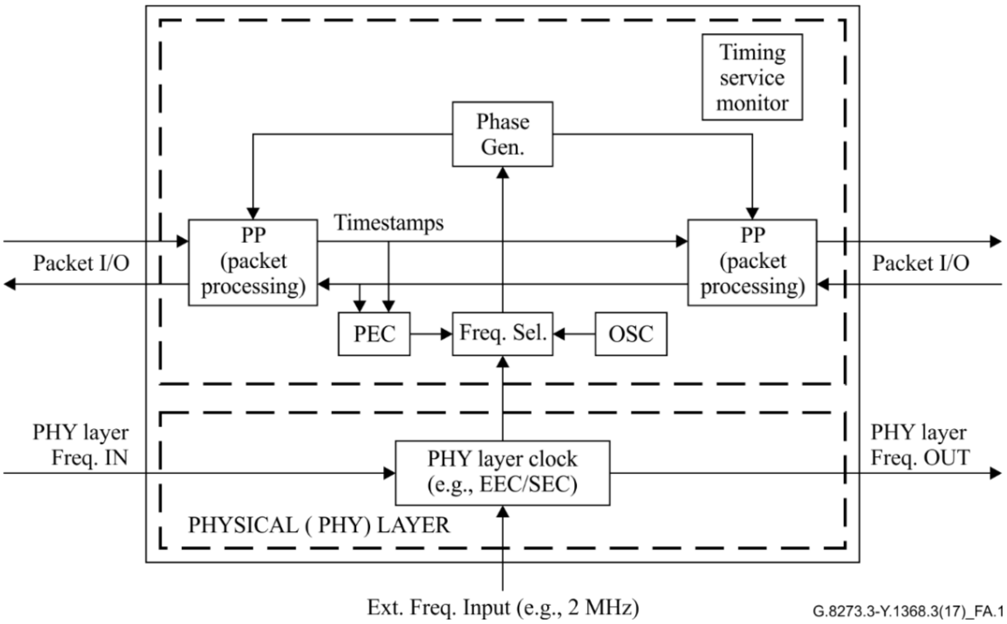

Figure A.1 – Transparent clock model

NOTE 1 – In Figure A.1, the physical layer frequency signal may be bidirectional for SyncE/SDH.

NOTE 2 – The "Physical layer clock" shown in Figure A.1 must comply with standard physical clock processing and management according to [ITU-T G.8262], [ITU-T G.8264] and [ITU-T G.781].

NOTE 3 – The implementation and use of a packet-based equipment clock (PEC) for a T-TC is optional.

NOTE 4 – This version of the Recommendation is based on physical layer support, and therefore it is required.

Figure A.1 shows a functional model of a telecom transparent clock. It is not intended to specify any specific implementation. Any implementation specific detail is outside the scope of this Recommendation.

The packet timing signal is processed by the packet processing blocks. The ingress timestamp for each Sync and Delay_req packet is sent to the egress packet processing blocks where it is used together with the egress timestamp to calculate the residence time for the frame. The timestamps are also sent to the PEC block for further processing. The frequency information carried in the timestamps is used in the PEC to generate the local frequency.

The frequency selector block may select either the frequency information recovered from the timestamps, or the frequency recovered from a physical layer clock (e.g., SyncE, SONET or SDH) or from a local oscillator.

The phase generator is used to generate the free-running time used in the packet processing (PP) blocks to generate the timestamps. The free-running time is not locked in time to any time reference, but is locked in frequency to the source selected by the freq. sel. block.

The timing service monitor is an optional feature which may provide monitoring of a timing service received by the clock according to key performance indicators. As an example, it may monitor the

PTP timing service by analysing the PTP timestamps and message rate from the PP block and raise an unusable alarm based on implementation specific criteria.

Appendix I

Traffic load test patterns

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

As the time error of a T-TC is affected by the size and asymmetry of the residence time calculation error, it is important to test the performance of a T-TC with cross traffic load.

The following traffic load patterns must be used when testing a T-TC. See Figure I.1 for a T-TC test set-up with cross traffic.

Cross traffic in both directions using maximum size frames and the same quality of service (QoS) class as the PTP traffic creating a 97% egress load on the PTP ports in bursts of 5 seconds. In addition to this, there should be an additional cross traffic load of 2% maximum frame sized frames of a lower priority then the PTP frames, creating overload on the egress ports. The traffic should be so that the 99% egress load happens only on one PTP port at a time to create the maximum asymmetry.

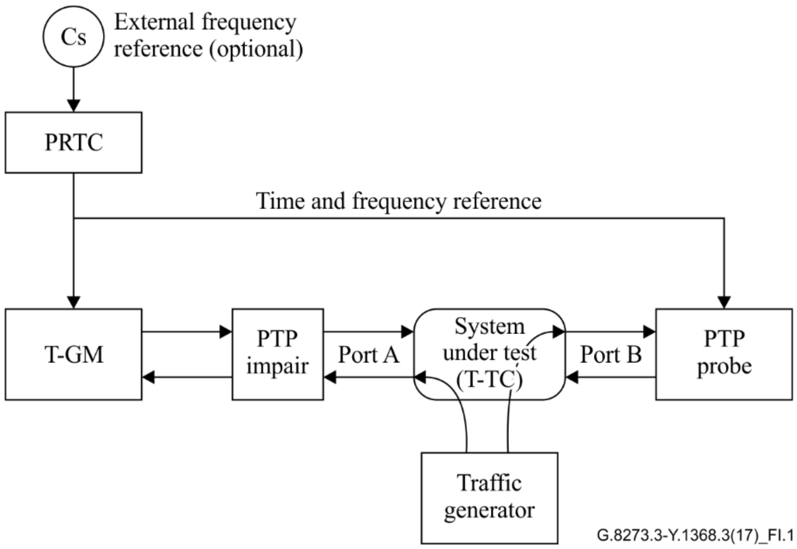

Figure I.1 – T-TC test set-up with cross traffic

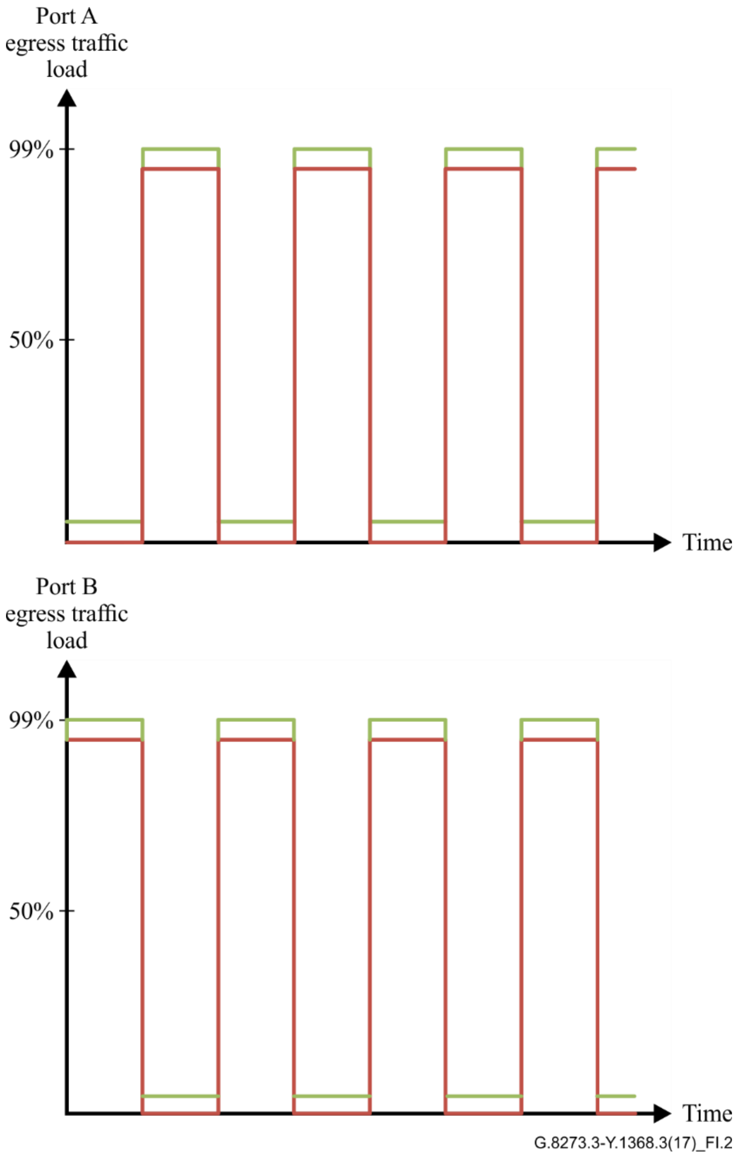

Figure I.2 – Cross traffic pattern

Figure I.2 shows cross traffic test patterns. Other test patterns are for further study.

Appendix II

Residence time

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

For the correct operation of a T-TC, the residence time (i.e., the time PTP event messages take to traverse the T-TC) needs to be controlled to be below a suitable value.

This is important, especially in case of cascaded T-TCs. One main reason is to control noise accumulation. As an example, during failures in the synchronous Ethernet network, a T-TC may operate with a frequency deviation of 2 ppm for a short period of time, and over 10 ms each T-TC would contribute a time error of 20 ns.

In addition, the control of residence time variation is important to limit the irregular inter-arrival period of the PTP messages received by a telecom boundary clock (T-BC) or by a telecom time slave clock (T-TSC) as this may impact their performance or lead to the generation of alarms.

A limit of 10 ms is generally indicated as suitable.

Appendix III

Performance estimation for cascaded media converters acting as T-TCs

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

[ITU-T G.8273] describes the "back-to-back" testing of devices such as media converters, where the connecting interface may not be Ethernet, and hence a suitable tester may not be available. This appendix describes how to estimate the budget to use for back-to-back testing of such devices, where each device is allocated the budget equivalent to a single T-TC. It is further assumed that these devices are frequency synchronized to each other using physical layer clock. A pair of such devices is modelled here as a pair of T-TCs.

NOTE – The analysis in this appendix is based on T-TCs of the same class, i.e., a chain containing solely class A or solely class B. The performance of cascaded clocks may depend on the specific media interconnecting the clocks.

III.1 Noise generation

The budget for the noise generation of a pair of cascaded T-TCs can be estimated as follows:

1) Constant time error limit (cTE):

   cTE accumulates linearly in a chain of devices. For example, if each device has a cTE of 50 ns, the total cTE after two devices will be 100 ns.

2) Dynamic time error limit – low pass filtered (dTE_L):

   dTE_L accumulates as noise power.

   The accumulation of maximum time interval error (MTIE) of dTE_L is approximately the square root of the sum of squares of MTIE of the individual dTE_L components. For example, if each device has a dTE_L whose MTIE is 40 ns, the MTIE of the total dTE_L after two devices is $\sqrt{(2 \cdot 40^2)} = 57$ ns.

   For the purposes of this budget, the value is rounded up to 60 ns.

   TDEV is for future study.

   NOTE – MTIE and TDEV are functions of the observation interval τ. In the examples of this section, MTIE and TDEV are constant, i.e., each can take on only a single value, over the respective ranges of observation interval of interest. Given this, the explicit indication of the dependence of MTIE and TDEV on τ can be omitted. If MTIE or TDEV vary with τ, the value at the desired observation interval should be used.

3) Dynamic time error limit – high pass filtered (dTE_H)

   The T-TC case does not involve any filtering of noise at cascaded devices, and therefore dTE_H accumulates as noise power like dTE_L.

   The accumulation of the peak-to-peak of dTE_H is approximately the square root of the sum of the squares of the peak-to-peak of the individual dTE_H components. For example, if each device has a dTE_H whose peak-to-peak is 70 ns, the peak-to-peak of the total dTE_H after two devices is $\sqrt{(2 \cdot 70^2)} = 99$ ns.

   For the purposes of this budget, the value is rounded up to 100 ns.

   TDEV is for future study.

4) Maximum absolute time error limit – unfiltered max|TE|

   The maximum absolute time error (max|TE|) is the maximum of the absolute value of the total time error, including all components, i.e., cTE, dTE_L, and dTE_H.

In calculating max|TE|, the symmetry of dTE_H must be considered. dTE_H is the result of passing dTE through a high-pass measurement filter. The high-pass filter removes any zero-frequency component, i.e., the time average, of dTE, which means that the time average of dTE_H is zero. However, in general dTE_H need not be symmetric, i.e., the peak (maximum) and trough (minimum) values of dTE_H need not have the same absolute value. In the symmetric case, the trough value is the negative of the peak value, and the peak-to-peak value is equal to twice the peak value. In this case, one-half the peak-to-peak value contributes to max|TE|. The other extreme is the completely asymmetric case, where the peak value is equal to the peak-to-peak value and the trough value is zero. In this case, the full peak-to-peak value contributes to max|TE|. The general case is somewhere between these two extremes.

The following two equations, denoted Method 1 and Method 2, show how max|TE| is calculated under the assumptions that dTE_H is completely asymmetric and dTE_H is symmetric, respectively. These equations follow Case 1 of Appendix IV of [ITU-T G.8271.1], which assumes that dTE_L is symmetric. The equations are based on Eq. (IV-13) of [ITU-T G.8271.1], except that, as indicated in 3) above, a T-TC does not do any filtering, and therefore the dTE_H component must be included for each T-TC when calculating the accumulated max|TE|.

Method 1 (dTE_H is assumed to be completely asymmetric, and the peak-to-peak value is used).

$$\max|\mathrm{TE}| = 2 \cdot \mathrm{cTE} + \sqrt{2\left(0.5 \cdot \mathrm{dTE_L MTIE}\right)^2 + 2\left(\mathrm{dTE_H}\right)^2}$$

Method 2 (dTE_H is assumed to be symmetric, and one-half of the peak-to-peak value is used).

$$\max|\mathrm{TE}| = 2 \cdot \mathrm{cTE} + \sqrt{2\left(0.5 \cdot \mathrm{dTE_L MTIE}\right)^2 + 2\left(0.5 \cdot \mathrm{dTE_H}\right)^2}$$

The value of max|TE| in Table III.1 is the average of the values computed using Methods 1 and 2.

Table III-1 summarises the results applied to the class A and class B T-TC. The values in Table III.1 are computed as described in points 1-4 above.

Table III.1 – Noise generation estimation for a pair of media converters

	Class A T-TC		**Class B T-TC**		**Class C T-TC**	
	Single T-TC	**Pair of media converters**	**Single T-TC**	**Pair of media converters**	**Single T-TC**	**Pair of media converters**
cTE (ns)	±50	±100 ns	±20 ns	±40 ns	±10 ns	±20 ns
dTE_L MTIE (ns)	40	60 ns	40 ns	60 ns	10 ns	14 ns
dTE_L TDEV (ns)	FFS	FFS	FFS	FFS	FFS	FFS
dTE_H (peak-to-peak, ns)	70	100	70	100	FFS	FFS
max|TE| (ns)	100 ns	180 ns	70 ns	120 ns	FFS	FFS

NOTE – The values for a single class A, class B, and class C T-TC are defined in clause 7.1. The values for a pair of media converters based on class A, class B, and class C T-TCs are obtained using the above equations.

III.2 Noise tolerance

For noise tolerance, the input stimulus should be the same as defined in clause 7.2, with none of the cascaded clocks raising alarms, switching references or going into holdover.

III.3 Noise transfer

The noise transfer response of a pair of cascaded transparent clocks is for further study.

III.4 Transient response and holdover performance

The transient response and holdover performance of pair of cascaded transparent clocks is for further study.

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