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## G.8273/Y.1368

**Corrigendum 1**  
(10/2020)

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Framework of phase and time clocks

**Corrigendum 1**

Recommendation ITU-T G.8273/Y.1368 (2018) –  
Corrigendum 1

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# Recommendation ITU-T G.8273/Y.1368

## Framework of phase and time clocks

### Corrigendum 1

#### Summary

Recommendation ITU-T G.8273/Y.1368 is a framework Recommendation for phase and time clocks for devices used in synchronizing network equipment that operate in the network architecture defined in Recommendations ITU-T G.8271, ITU-T G.8275 and the ITU-T G.8271.x-series of Recommendations.

Amendment 1 provides the following updates:

- Updates the References clause
- Adds Appendix IV
- Editorial changes in Annex B, and minor edits throughout the document

Corrigendum 1 corrects a reference in clause 6.

#### History

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#### Keywords

Phase and time clocks, testing and measurement.

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# Recommendation ITU-T G.8273/Y.1368

## Framework of phase and time clocks

### Corrigendum 1

*Editorial note: This is a complete-text publication. Modifications introduced by this corrigendum are shown in revision marks relative to Recommendation ITU-T G. 8273/Y.1368 (2018) plus its Amendment 1 (2020).*

#### 1 Scope

This Recommendation is a framework Recommendation for phase and time clocks for devices used in synchronizing network equipment that operate in the network architecture defined in [ITU-T G.8271], [ITU-T G.8275] and the ITU-T G.8271.x-series of Recommendations.

This Recommendation serves as a framework for phase and time clocks defined in the ITU-T G.8273.x-series. It includes annexes with detailed testing and measurement methods of phase and time clocks.

#### 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.810] Recommendation ITU-T G.810 (1996), *Definitions and terminology for synchronization networks*.
- [ITU-T G.8260] Recommendation ITU-T G.8260 (2020), *Definitions and terminology for synchronization in 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.8272] Recommendation ITU-T G.8272/Y.1367 (2018), *Timing characteristics of primary reference time clocks*.
- [ITU-T G.8273.2] Recommendation ITU-T G.8273.2/Y.1368.2 (2020), *Timing characteristics of telecom boundary clocks and telecom time slave clocks for use with full timing support from the network*.
- [ITU-T G.8273.3] Recommendation ITU-T G.8273.3/Y.1368.3 (2017), *Timing characteristics of telecom transparent clocks*.
- [ITU-T G.8275] Recommendation ITU-T G.8275/Y.1369 (2017), *Architecture and requirements for packet-based time and phase distribution*.
- [IEEE 1588-2008] IEEE 1588-2008, *IEEE Standard for a Precision Clock Synchronization Protocol for Networked Measurement and Control Systems*.

### 3 Definitions

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

### 4 Abbreviations and acronyms

This Recommendation uses the following abbreviations and acronyms:

1PPS	One Pulse Per Second
APTSC	Assisted Partial Timing Support Slave Clock
Cs	Caesium
cTE	constant Time Error
DUT	Device Under Test
ESMC	Ethernet Synchronization Message Channel
FFO	Fractional Frequency Offset
GM	Grandmaster
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
MTIE	Maximum Time Interval Error
PPS	Pulse Per Second
PRC	Primary Reference Clock
PRTC	Primary Reference Time Clock
PTP	Precision Time Protocol
QL	Quality Level
SUT	System Under Test
SyncE	Synchronous Ethernet
TDEV	Time Deviation
ToD	Time of Day
T-BC	Telecom Boundary Clock
T-BC-A	Telecom Boundary Clock – Assisted
T-BC-P	Telecom Boundary Clock – Partial support
T-GM	Telecom Grandmaster
T-TC	Telecom Transparent Clock
T-TSC	Telecom Time Slave Clock
T-TSC-A	Telecom Time Slave Clock – Assisted
T-TSC-P	Telecom Time Slave Clock – Partial support

### 5 Conventions

Within this Recommendation, the following conventions are used: the term precision time protocol (PTP) refers to the PTP protocol defined in [IEEE 1588-2008].

The terms dynamic time error and time noise are used interchangeably throughout this Recommendation to indicate the jitter and wander components of the timing signal.

## **6 General introduction of phase and time clocks**

This Recommendation serves as a framework for phase and time clocks that have been defined or are to be defined in the ITU-T G.8273.x-series of Recommendations.

The focus of this Recommendation is on packet-based methods for transferring time/phase. Specific methods based on the precision time protocol (PTP) [IEEE 1588-2008] are considered.

The ITU-T G.8273.x-series of Recommendations define the following; however, it is important to note that as of the date of publication, there are two documents mentioned below that have not been approved yet, they are still under study, thus they may be subject to change:

- Telecom grandmaster specification. The telecom grandmaster (T-GM) is a device consisting of a grandmaster as defined in [IEEE1588-2008] with additional performance characteristics. The details of T-GM are specified [ITU-T G.8272]. Other types of T-GM are for further study and are expected to be specified in [ITU-T G.8273.1] (currently under study).
- Telecom boundary clock specification. The telecom boundary clock (T-BC) is a device consisting of a boundary clock as defined in [IEEE1588-2008] with additional performance characteristics such as noise generation, noise tolerance, noise transfer, transient response and holdover. [ITU-T G.8273.2] specifies T-BC.
- Telecom transparent clock specification. The telecom transparent clock (T-TC) is a device consisting of a transparent clock as defined in [IEEE1588-2008] with additional performance characteristics. [ITU-T G.8273.3<sup>4</sup>] specifies T-TC.
- Telecom time slave clock specification. The telecom time slave clock (T-TSC) is a device consisting of a slave clock as defined in [IEEE1588-2008] with additional performance characteristics. [ITU-T G.8273.2] specifies T-TSC.
- Partial timing support telecom boundary clocks (telecom boundary clock – partial support (T-BC-P), telecom boundary clock – assisted (T-BC-A)) and telecom time slave clocks (telecom time slave clock – partial support (T-TSC-P), telecom time slave clock – assisted (T-TSC-A)). The details of these clocks are for further study and are expected to be specified in [ITU-T G.8273.4] (currently under study).

## Annex A

### Testing and measurement of time/phase clocks

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

#### A.1 Introduction

Measurement of time/phase behaviour of clocks is substantively different from measurement of frequency behaviour of clocks. The basis for the measurement in both cases is *time error* but for frequency-based measurements the *time interval error* information is extracted and the typical metrics used are maximum time interval error (MTIE) and time deviation (TDEV). These metrics are appropriate since the absolute value of time error is moot for frequency. In fact, MTIE can be viewed as a stability measure based on peak-to-peak time error (over an observation interval) and the "average" value is of little consequence. In the case of TDEV, the goal is to characterize the noise processes and consequently it is advantageous to suppress the mean *time error* as well as the (average) frequency offset.

Frequency metrics, such as MTIE, TDEV and fractional frequency offset (FFO) can be applied to time/phase clocks and such measurements may have value when assessing the stability of a time clock; such metrics are not sufficient to characterize the time error of a time/phase clock. One such metric that is distinct from frequency metrics is the *constant time error*. The use of constant, dynamic and frequency metrics to characterize stability of a time/phase clock is for further study.

The concentration in this Recommendation is on packet-based methods for transferring time/phase. For specificity, methods based on PTP [IEEE 1588-2008] are considered.

NOTE – Here emphasis is placed on grandmaster, boundary clocks and transparent clocks. Slave clocks are left for further study.

##### A.1.1 Master port time-stamp error

There are four time stamps that are relevant in PTP. These are:

- Associated with the *SYNC* message:
  - 1)  $T_1$ : time-of-departure from master port;
  - 2)  $T_2$ : time-of-arrival at slave port.
- Associated with *DELAY\_REQUEST* message:
  - 3)  $T_3$ : time-of-departure from slave port;
  - 4)  $T_4$ : time-of-arrival at master port.

Of these time stamps,  $T_2$  and  $T_3$  are struck at the slave port and are not visible externally ( $T_3$  may be visible from some devices). Time stamps  $T_1$  and  $T_4$  are visible externally.  $T_1$  is available in the *SYNC* (or *FOLLOW\_UP*) message and  $T_4$  is available in the *DELAY\_RESPONSE* message. The accuracy of these time stamps is quantified by the difference between the time stamp as struck and the system under test time clock at the actual time-of-departure or time-of-arrival of the *SYNC* and *DELAY\_REQUEST* packets, respectively. The measurement device can utilize as its time reference for measurement the same reference provided to the grandmaster as described in Annex B.

It should be noted that  $T_1$  and  $T_4$  are not single time-stamp values.  $T_1$  is the presentation by the master port of its best estimate of the time-of-departure of the *SYNC* message. This shall be presented in the *originTimestamp* plus *correctionField* of the *SYNC* message (in one step clocks) or in the *preciseOriginTimestamp* plus *correctionField* of the *FOLLOW\_UP* message (in 2-step clocks).  $T_4$  is the presentation by the master port of its best estimate of the time-of-arrival of the *DELAY\_REQUEST* message. This shall be presented in the *receiveTimestamp* of the *DELAY\_RESPONSE* message plus

the difference between the *correctionField* of the *DELAY\_REQUEST* message and the *correctionField* of the *DELAY\_RESPONSE* message.

Since there are multiple time stamps used to represent the  $T_1$  and  $T_4$  values, additional error budgeting beyond simple single time-stamp granularity may be required.

A measurement device placed at a calibrated distance from the master port can estimate the time-of-departure of a *SYNC* message from the master port by time-stamping the passage of the *SYNC* message. Denote this measurement by  $T_{1REF}$ . By parsing the *SYNC* message (or *FOLLOW\_UP*), the time-of-departure of the *SYNC* message as struck by the master port,  $T_1$ , is established. The accuracy of the time stamp is quantified by the time error (sequence)  $TE_1$  given by:

$$TE_1 = T_1 - T_{1REF} \quad (A.1.1)$$

The observed time error is compared against the specified limit  $Y_1$ . The pass criterion is:

$$|TE_1| \leq Y_1 \quad (A.1.2)$$

The limit  $Y_1$  is application dependent and is defined in the relevant clock specification. As recommended in [IEEE 1588-2008],  $Y_1$  is commensurate with the required accuracy of the application. The further allocation to constant time error and dynamic time error (time noise) and systematic errors is for further study.

A measurement device placed at a calibrated distance from the master port can estimate the time-of-arrival of a *DELAY\_REQUEST* message from the master port by time-stamping the passage of the *DELAY\_REQUEST* message. Denote this measurement by  $T_{4REF}$ . By parsing the *DELAY\_RESPONSE* message, the time-of-arrival of the *DELAY\_REQUEST* message as struck by the master port,  $T_4$ , is established. The accuracy of the time stamp is quantified by the time error (sequence)  $TE_4$  given by:

$$TE_4 = T_4 - T_{4REF} \quad (A.1.3)$$

The observed time error is compared against the specified limit  $Y_4$ . The pass criterion is:

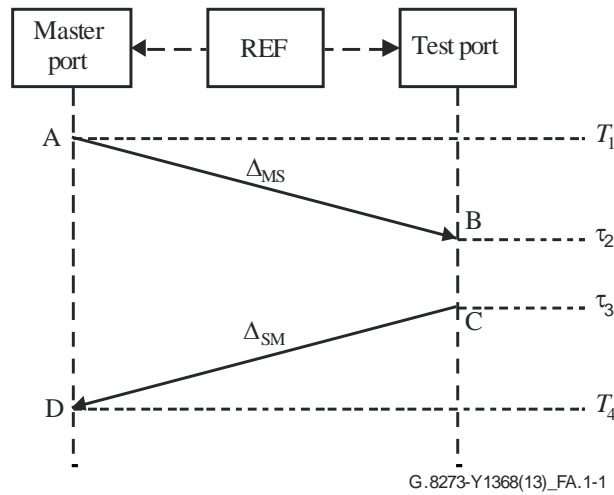
$$|TE_4| \leq Y_4 \quad (A.1.4)$$

The limit  $Y_4$  is application dependent and is defined in the relevant clock specification. As recommended in [IEEE 1588-2008],  $Y_4$  is commensurate with the required accuracy of the application. The further allocation to constant time error and dynamic time error (time noise) and systematic errors is for further study.

Measuring the time-error  $TE_1$  is achieved by time-stamping the passage of a *SYNC* message at a calibrated distance from the master port. Similarly,  $TE_4$  is measured by time-stamping the passage of a *DELAY\_REQUEST* message at a calibrated distance from the master port. If the test device is a PTP probe, the relevant time stamps generated in the probe would be the time-of-arrival of a *SYNC* message from the master and the time-of-departure of a *DELAY\_REQUEST* message to the master. This is depicted in Figure A.1-1.

Guidelines for the measurement include:

- a) The master device and the test device are provided with a common time/phase reference and it is assumed that any synchronization error associated with locking to this reference is negligible. Such synchronization errors should be maintained to a level to facilitate the verification of the time error limit. Any systematic errors associated with synchronization and one pulse per second (1PPS) interface should be accounted for.
- b) The test device must be calibrated and the time-stamp accuracy and granularity of time stamps struck by the test device should be maintained to a level to facilitate the verification of the time error limit.
- c) Annex B includes several testing configurations identifying the manner in which an external time/phase reference is provided to the different equipment involved.



**Figure A.1-1 – Depicting the situation where the system under test is connected to a test device and PTP messages are exchanged**

At time "A" the master sends a *SYNC* message with time stamp  $T_1$ . The packet arrives at the test device at "B" and the time-of-arrival noted as  $\tau_2$ . The estimate of the forward transmission delay,  $\Delta_F$ , is given by:

$$\Delta_F = \tau_2 - T_1 \quad (\text{A.1.5})$$

The test device sends a *DELAY\_REQUEST* packet at "C" and the time-of-departure noted as  $\tau_3$ . The time-of-arrival at the master, at "D", is noted as  $T_4$  and this value is returned in the *DELAY\_RESPONSE* message. The estimate of reverse transmission delay,  $\Delta_R$ , is given by:

$$\Delta_R = T_4 - \tau_3 \quad (\text{A.1.6})$$

In order to verify the accuracy of the time stamps  $T_1$  and  $T_4$ , the transmission delays in the interconnecting medium (e.g., fibre) have to be controlled. Specifically, the cable length is calibrated and the delays  $\Delta_{MS}$  and  $\Delta_{SM}$  are known to have a reasonable level of accuracy. Equations A.1.5 and A.1.6 provide estimates of transmission delays based on the time stamps struck by the master and therefore the time-stamp accuracy is confirmed if:

$$\begin{aligned} |\Delta_F - \Delta_{MS}| &< Y_1 \\ |\Delta_R - \Delta_{SM}| &< Y_4 \end{aligned} \quad (\text{A.1.7})$$

where  $Y_1$  and  $Y_4$  are the prescribed limits for time-stamp accuracy. The further allocation to constant time error and dynamic time error (time noise) is for further study.

### A.1.2 Master port time-transfer error

Considering a slave device downstream from the master port, the time transfer time error is dependent indirectly on the accuracy of time stamps  $T_1$  and  $T_4$  and directly on a combination thereof. The time transfer time error can be measured by providing a common time reference to the master port and monitoring device (test port) as shown in Figure A.1-1. Assuming that the cable delay is symmetric, i.e.,  $\Delta_{MS} = \Delta_{SM} = \Delta$ , the time error signal,  $T_{err}(t)$  can be expressed as:

$$T_{err}(t) = \frac{(T_4(t) + T_1(t)) - (\tau_3(t) + \tau_2(t))}{2} \quad (\text{A.1.8})$$

where the terms  $T_4(t)$ ,  $T_1(t)$ ,  $\tau_3(t)$ , and  $\tau_2(t)$  represent the implicit signals corresponding to the time-stamping processes. Calculation of wander metrics is conventionally performed on samples of  $T_{err}(t)$ , namely  $\{T_{err}(k\tau_0)\}$ , where the samples are taken on a uniform time grid with sampling interval  $\tau_0 < (1/30)$ .

However, the packet rates in the two directions can be different and the relative phasing non-deterministic. Consequently, denoting the (symmetric) cable delay by  $\Delta$ , the time error components  $TE_1$  and  $TE_4$  are computed as:

$$\begin{aligned} TE_1(n) &= T_1(n) + \Delta - \tau_2(n) \\ TE_4(m) &= T_4(m) - \Delta - \tau_3(m) \end{aligned} \quad (\text{A.1.9})$$

The indices  $n$  and  $m$  indicate the packet sequence number and serve as a sampling index for the different time signals. The time transfer error is determined by a combination of the two discrete-time sequences  $\{TE_1(n)\}$  and  $\{TE_4(m)\}$ . Depending on the configured parameters of the IEEE-1588v2 flow, the two sequences could have different sampling rates and non-overlapping grids of sampling points. The methodology for combining the sequences is for further study.

The time error can be considered in two parts, one is the *constant time error* and the other is the *dynamic time error* or *time noise*. The time noise generation requirement is for further study. The constant time error component of the time error is derived by combining the constant time error of each sequence computed separately.

For a master port, the *constant time error transfer* requirement is satisfied if:

$$\frac{|(TE_1(n)) + (TE_4(m))|}{2} < X_{\text{CONSTANT}} \quad (\text{A.1.10})$$

where the notation  $< >$  is used for the constant time error estimation and  $X_{\text{CONSTANT}}$  is the prescribed limit for constant time error generation for the master port provided in the appropriate Recommendation of the ITU-T G.8273.x series of Recommendations.

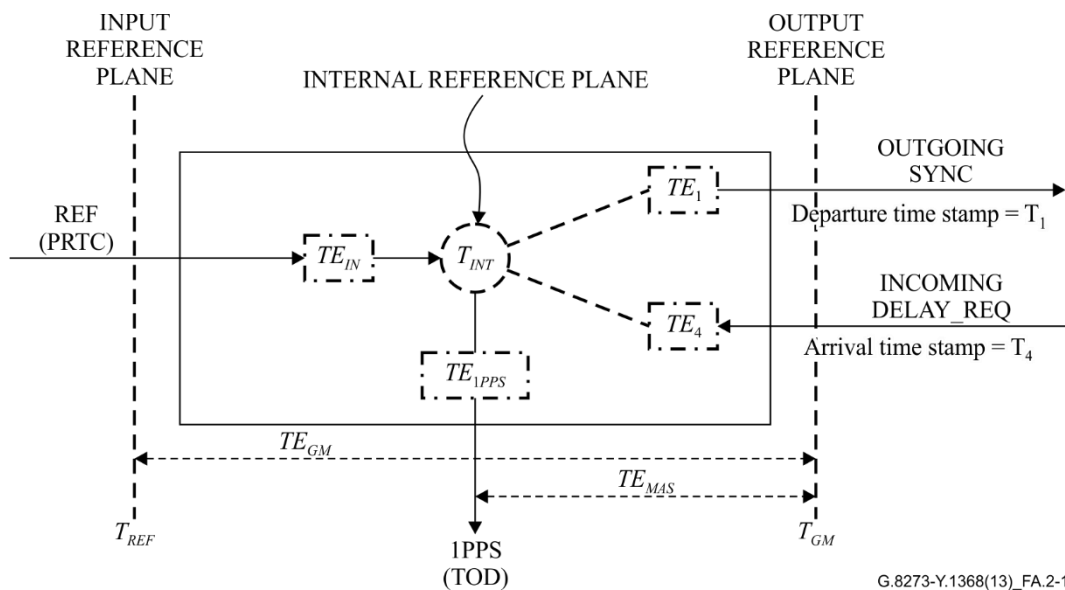
The implication of satisfying Equation A.1.10 is that the master port is capable of delivering time to a downstream slave that is within  $X_{\text{CONSTANT}}$  of the underlying time clock of the master port, in terms of constant time error.

## A.2 Grandmaster clocks

The time error generation requirement for a grandmaster (GM) clock is  $X_{GM}$  ns. That is,

$$|T_{GM}(t) - T_{REF}(t)| < X_{GM} \quad (\text{A.2.1})$$

where " $t$ " represents the mathematical progression of time as an independent variable,  $T_{REF}$  is the time value of the reference provided to the GM and  $T_{GM}$  is the time value of the GM. The value for  $X_{GM}$  is specified in the Recommendation addressing grandmaster clocks.



G.8273-Y.1368(13)\_FA.2-1

**Figure A.2-1 – Noise generation model for a grandmaster clock**

A grandmaster clock receives its reference from a primary reference time clock (PRTC) or, in the event that the T-GM and PRTC are combined, the reference may come from other sources such as a global navigation satellite system (GNSS) receiver. The internal master time of the T-GM,  $T_{GM}$ , is available via a 1PPS (and time of day (ToD)) interface and may be used to monitor the performance of the internal time of the T-GM,  $T_{INT}$ . There may be uncertainty in this output due to the  $TE_{1PPS}$  term. The item  $TE_{IN}$  represents any time error associated with the T-GM deriving its internal time clock from the reference. Any time noise attributed to signal processing and/or a local oscillator is included in  $TE_{IN}$ . The master port of the T-GM provides time stamps associated with the time-of-departure of SYNC packets ( $T_1$ ) and the time-of-arrival of DELAY\_REQUEST packets ( $T_4$ ) and there could be a noise generation associated with each of time stamps,  $TE_1$  and  $TE_4$ , respectively.

The *effective* time error generation of the GM,  $TE_{GM}$ , is a combination of these individual time error generation components. The noise generation in the master side of the clock,  $TE_{MAS}$  is a function of the combination of  $TE_1$  and  $TE_4$ ; the methodology for combining them is for further study. In addition to clock noise arising from any error in the reference, additional time error may be introduced by the local clock operation such as the clock noise introduced by the local oscillator or via the physical-layer reference (e.g., SyncE) and these are generally manifested in the internal clock time error,  $TE_{IN}$ . The overall T-GM noise generation limit is satisfied if:

$$|TE_{IN} + TE_{MAS}| < X_{GM} \quad (A.2.2)$$

where  $X_{GM}$  is a representation of the allowed time error (such as constant or dynamic) generated by the T-GM, and may be specified as either a value or mask depending on the parameter being specified. The specific values for  $X_{GM}$  is for further study.

The noise generation behaviour of a GM can also be measured by providing an accurate time at the input reference plane ( $T_{REF}$ ), or by using a monitoring device to recover the time delivered at the input reference plane ( $T_{REF}$ ), and comparing this with the time delivered by the T-GM at the output reference plane ( $T_{GM}$ ).

Where a mechanism is provided to establish  $T_{REF}$  accurately, this provides the reference time for the test device that monitors the master side of the T-GM under test. That is, using  $T_{REF}$  as the time reference, the test device at the output reference plane develops  $\tau_2$  and  $\tau_3$  and observes  $T_1$  and  $T_4$  (refer to Figure A.2-2 for definition of  $\tau_2$  and  $\tau_3$ ). Denoting the (symmetric) cable delay by  $\Delta$ , the time error components  $TE_1$  and  $TE_4$  are computed as:

$$\begin{aligned} TE_1(n) &= T_1(n) + \Delta - \tau_2(n) \\ TE_4(m) &= T_4(m) - \Delta - \tau_3(m) \end{aligned} \quad (A.2.3)$$

The indices  $n$  and  $m$  indicate the packet sequence number. The time error of the T-GM is determined by a combination of the two discrete-time sequences  $\{TE_1(n)\}$  and  $\{TE_4(m)\}$ . Depending on the configured parameters of the IEEE 1588v2 flow, the two sequences could have different sampling rates and non-overlapping grids of sampling points and the methodology for combining the separate time error sequences for generating the T-GM time error function is for further study.

The time error consists of two components:

- 1) constant time error, and
- 2) time noise.

The time noise (dynamic time error) generation requirement is for further study. Time noise can be evaluated with metrics such as MTIE and TDEV. Their use is for further study.

The constant time error component of the composite time error is computed as the constant time error of each sequence separately following the procedure described in clause 3.1.20 of [ITU-T G.8260]. The constant time error generation requirement is satisfied if:

$$\frac{|\langle TE_1(n) \rangle + \langle TE_4(m) \rangle|}{2} < X_{GM-CONSTANT} \quad (A.2.4)$$

where the notation  $\langle \rangle$  is used for the constant time error estimation and  $X_{GM-CONSTANT}$  is the prescribed limit for constant time error generation for the T-GM;  $X_{GM-CONSTANT}$  is for further study.

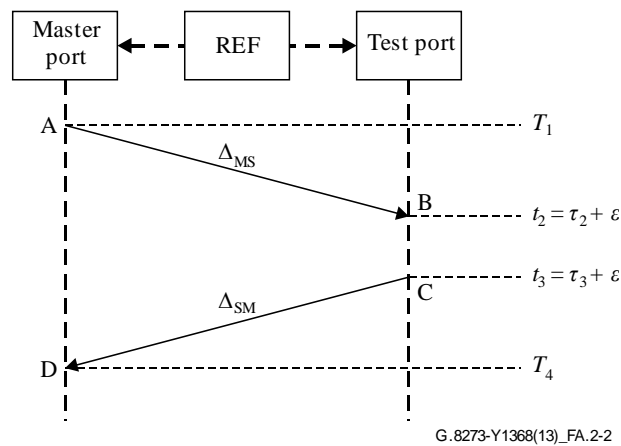
(The expression  $\frac{|\langle TE_1(n) \rangle + \langle TE_4(m) \rangle|}{2}$  represents half the asymmetry between the constant time errors in the forward and reverse directions, which in this case is total constant time error introduced.)

The implication of satisfying Equation A.2.4 is that the T-GM is capable of delivering time to a downstream slave that is within  $X_{GM-CONSTANT}$  of the reference input to the T-GM, in terms of constant time error.

The internal time clock of the GM may not be visible directly and the GM time must be ascertained from the manner in which it manifests itself at a port. That is, the GM time is examined by evaluating the time stamps struck by the GM and provided in messages. These are:

- *SYNC* message: The time stamp  $T_1$  represents the time stamp struck by the GM at the time-of-egress (time-of-departure) of the *SYNC* message and is observable externally in either the *SYNC* message itself (1-step clock) or in a *FOLLOW\_UP* message (2-step clock).
- *DELAY\_REQUEST*: The time stamp  $T_4$  represents the time stamp struck by the GM at the time-of-ingress (time-of-arrival) of the *DELAY\_REQUEST* message and is observable externally in the *DELAY\_RESPONSE* message.

One approach for achieving this estimate is based on the following. With reference to Figure A.2-2, the same reference is provided to both the unit under test (the GM), as well as the equipment used for measurement. The test device and the GM are connected over suitable media (e.g., fibre) and the length (in terms of delay) of the medium from master to test point is denoted by  $\Delta_{MS}$  and the reverse direction by  $\Delta_{SM}$ . The quantity  $\varepsilon$  represents the time-offset between the system under test (SUT) (GM) and the test device.



**Figure A.2-2 – Depicting the situation where the SUT is connected to test device and PTP messages are exchanged**

At time "A" the master sends a *SYNC* message with time stamp  $T_1$ . The packet arrives at the test device at "B" and the time-of-arrival noted as  $\tau_2$ . The equivalent time at the master is  $t_2$ , given by:

$$t_2 = \tau_2 + \varepsilon \quad (\text{A.2.5})$$

The test device sends a *DELAY\_REQUEST* packet at "C" and the time-of-departure noted as  $\tau_3$  and the equivalent time at the master,  $t_3$ , is given by:

$$t_3 = \tau_3 + \varepsilon \quad (\text{A.2.6})$$

The time-of-arrival at the master, at "D", is noted as  $T_4$  and this value returned in the *DELAY\_RESPONSE* message.

In order to verify GM operation, the transmission delays in the interconnecting medium (e.g., fibre) have to be controlled. Two cases are considered.

In CASE 1, the cable length is calibrated and the delays  $\Delta_{MS}$  and  $\Delta_{SM}$  are known to have a reasonable level of accuracy. Then in CASE 1, the GM performance is validated if:

$$\begin{aligned} |T_1 - \tau_2 + \Delta_{MS}| &< Y_1 \\ |T_4 - \tau_3 - \Delta_{SM}| &< Y_4 \end{aligned} \quad (\text{A.2.7})$$

In CASE 2 the interconnecting cable is calibrated so that the two directions are symmetric, with the absolute delay being known only approximately. In this case a necessary, but not sufficient, condition for the GM to be considered operating correctly is, heuristically:

$$\frac{|(T_1 + T_4) - (\tau_2 + \tau_3)|}{2} < X_{GM} \quad (\text{A.2.8})$$

$X_{GM}$  represents the actual requirement and it is for further study.

The reason for the qualification "not sufficient" is that the GM could strike time stamps  $T_1$  and  $T_4$  with significant error in each but which are equal and opposite. The alignment of packet time-stamp samples in the sampling rate and sampling grid is for further study.

### A.2.1 Grandmaster time stamp error

The time stamps generated should satisfy the following limits:

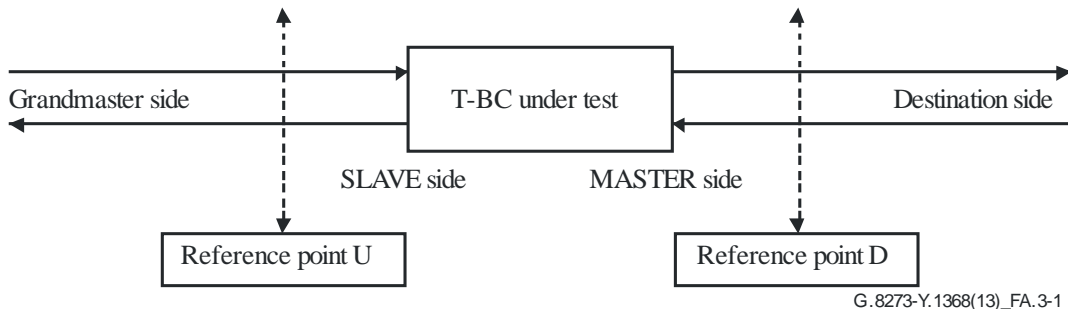
$$\begin{aligned} |T_1[n] - T_{1REF}[n]| &< Y_1 \\ |T_4[m] - T_{4REF}[m]| &< Y_4 \end{aligned} \quad (\text{A.2.9})$$

where the "REF" in the subscript is used to indicate the ideal value for the time stamp based on the PRTC reference signal input to the GM at network reference point A. Suitable values for  $Y_1$  and  $Y_4$  and the allocation to constant time error and dynamic time error (time noise) are for further study.

The indices "n" and "m" identify the individual packets (messages) being observed. The rates of the SYNC messages and DELAY\_REQUEST/DELAY\_RESPONSE messages may be different.

### A.3 Boundary clocks

A boundary clock (T-BC) can be viewed as a master clock that derives its timing reference from its slave using PTP packet exchanges with an upstream master. The same mathematical approach used for GMs above can be applied provided the test device derives its timing reference from exactly the same packet timing signal as the T-BC under test. The scenario is depicted in Figure A.3-1. At reference point "D" (for "downstream") the test device establishes the time as provided by the MASTER side of the T-BC. Denote this by  $T_{MAS}$ . It is required that, as a minimum, the interconnecting medium (e.g., fibre) between the T-BC master port and the reference point D is calibrated to be symmetric.



G.8273-Y.1368(13)\_FA.3-1

**Figure A.3-1 – Demarcation of measurement points for testing BC performance**

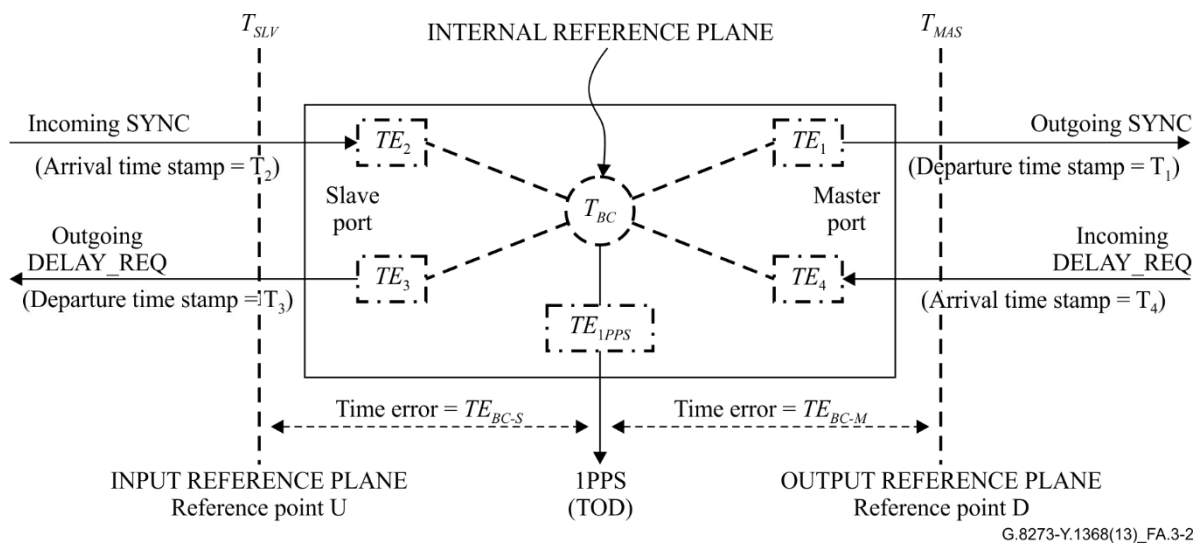
At reference point "U" (for "upstream"), a mechanism must be in place to measure the time at U as provided by the upstream master. It is assumed that, as a minimum, the interconnecting medium (e.g., fibre) between the T-BC slave port and the reference point U is calibrated to be symmetric. Given this calibration, the time,  $T_{SLV}$ , delivered by upstream master to the slave is established.

For satisfactory operation of the T-BC, there will be a requirement of the form:

$$|T_{MAS}(t) - T_{SLV}(t)| < X_{BC} \text{ (ns)} \quad (\text{A.3.1})$$

where  $X_{BC}$  is a representation of the allowed time error (such as constant or dynamic) generated by the T-BC, and may be specified as either a value or mask depending on the parameter being specified. The specific values for  $X_{BC}$  are for further study.

A simplified depiction of the time error generation in a boundary clock is shown in Figure A.3-2 below.  $T_{SLV}$  represents the time delivered by the upstream master to reference point U and  $T_{MAS}$  represents the time delivered by the T-BC to reference point D.



**Figure A.3-2 – Time error generation components in a boundary clock**

The boundary clock receives its reference from an upstream master clock. The internal system time of the T-BC,  $T_{BC}$ , is generally available via a 1PPS (and ToD) interface and may be used to monitor the performance of the internal time of the T-BC,  $T_{BC}$ . There may be uncertainty in this output due to the  $TE_{1PPS}$  term. The slave port of the T-BC generates time stamps associated with the time-of-arrival of *SYNC* packets ( $T_2$ ) and time-of-departure of *DELAY\_REQUEST* packets ( $T_3$ ). These time stamps are not available externally though there could be noise generation associated with each of time stamps  $TE_2$  and  $TE_3$ , respectively. Denote the time error of the slave clock, with respect to the input reference plane, by  $TE_{BC-S}$ .

Assuming that the input reference plane (reference point U) has symmetric or calibrated delays between the plane and the BC slave port, a test system can provide an accurate time input or a monitoring device placed there can establish the correct value for  $T_{SLV}$  and the effective time error generation in the slave clock portion of the T-BC can be measured by comparing  $T_{SLV}$  and the 1PPS output of the T-BC.

The master port of the T-BC provides time stamps associated with the time-of-departure of *SYNC* packets ( $T_1$ ) and time-of-arrival of *DELAY\_REQUEST* packets ( $T_4$ ) and there could be noise generation associated with each of time stamps,  $TE_1$  and  $TE_4$ , respectively. If these errors are equal and opposite, they do not necessarily contribute to the time transfer error relative to  $T_{BC}$ , denoted by  $TE_{BC-M}$ , in the timing signal provided by the T-BC to downstream equipment. Any asymmetric and/or

time-variable components in  $TE_1$  and  $TE_4$  can lead to constant time error and dynamic time error components of  $TE_{BC-M}$ .

The *effective* time error generation of the T-BC,  $TE_{BC}$ , is a combination of the individual time error generation components associated with the slave port plus the master port. In addition to clock noise arising from timing signal errors, additional time errors may be introduced by the local clock operation such as the clock noise introduced by the local oscillator or via the physical-layer reference (e.g., SyncE) and these are generally manifested in the slave side time error,  $TE_{BC-S}$ . The overall T-BC noise generation limit is satisfied if:

$$|TE_{BC-S} + TE_{BC-M}| < X_{BC} \quad (A.3.2)$$

The noise generation behaviour of a T-BC can also be measured by providing an accurate time at reference point U ( $T_{SLV}$ ) or using a monitoring device to recover the time delivered at reference point U ( $T_{SLV}$ ), as well as recovering the time delivered by the T-BC at reference point D ( $T_{MAS}$ ).

Provided that a mechanism is provided to establish  $T_{SLV}$  accurately, this provides the reference time for the test device that monitors the master side of the T-BC under test and the methodology established for testing GMs can be reapplied. That is, using  $T_{SLV}$  as the time reference, the test device at reference point D develops  $\tau_2$  and  $\tau_3$  and observes  $T_1$  and  $T_4$  (see Figure A.2-2 in clause A.2). Denoting the (symmetric) cable delay by  $\Delta$ , the time error components  $TE_1$  and  $TE_4$  are computed as:

$$\begin{aligned} TE_1(n) &= T_1(n) + \Delta - \tau_2(n) \\ TE_4(m) &= T_4(m) - \Delta - \tau_3(m) \end{aligned} \quad (A.3.3)$$

The indices  $n$  and  $m$  indicate the packet sequence number. The time error of the T-BC is determined by a combination of the two discrete-time sequences  $\{TE_1(n)\}$  and  $\{TE_4(m)\}$ . Depending on the configured parameters of the IEEE 1588v2 flow, the two sequences could have different sampling rates and non-overlapping grids of sampling points, and the methodology for combining the separate time error sequences for generating the T-BC time error function is for further study.

The time noise (dynamic time error) generation requirement is for further study.

The constant time error component of the time error is derived by combining the constant time error of each sequence computed separately.

For a T-BC, the constant time error generation requirement is satisfied if

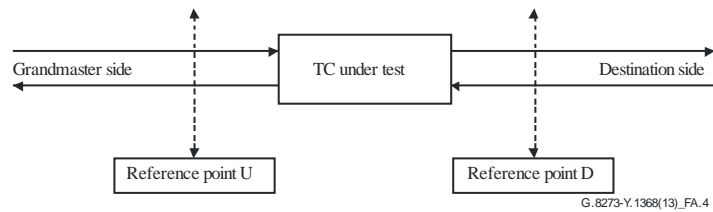
$$\frac{|\langle TE_1(n) \rangle + \langle TE_4(m) \rangle|}{2} < X_{BC-CONSTANT} \quad (A.3.4)$$

where the notation  $\langle \rangle$  is used for the constant time error estimation and  $X_{BC-CONSTANT}$ , the prescribed limit for constant time error generation for the T-BC, is for further study.

The implication of satisfying Equation A.3.4 is that the T-BC is capable of delivering time to a downstream slave that is within  $X_{BC-CONSTANT}$  of the time delivered by the upstream master clock to the T-BC, in terms of constant time error.

#### A.4 Transparent clocks

The primary purpose of a transparent clock (TC) is to provide on-path support for packet-based timing transfer based on PTP [IEEE 1588-2008]. This is achieved by adjusting the *correction\_field* by an amount equal to the residence time. See Figure A.4-1.



**Figure A.4 – Demarcation of measurement points for testing TC performance**

Assuming that the cable lengths between the reference points U and the TC under test are symmetric and that the cable lengths between the reference points D and the TC under test are symmetric, a slave clock at point U will exhibit a time-offset from the master (on the grandmaster side) of  $T_U$ . Likewise, a slave clock at point D will exhibit a time-offset from the same master of  $T_D$ .

For satisfactory operation of the TC, there will be a requirement of the form:

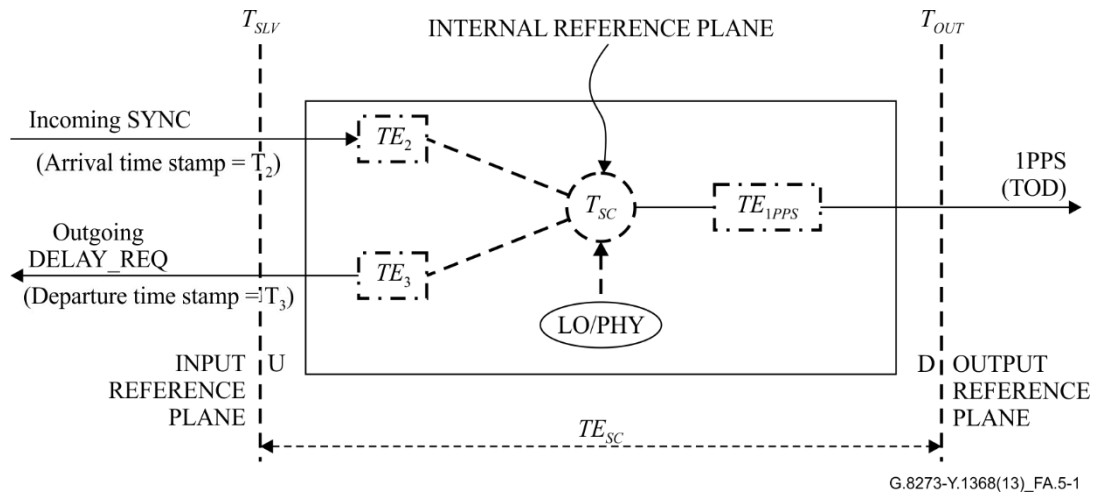
$$|T_U(t) - T_D(t)| < X_{TC} \text{ (ns)} \quad (\text{A.4.1})$$

where  $X_{TC}$  is a representation of the allowed time error (such as constant or dynamic) generated by the T-TC, and may be specified as either a value or mask depending on the parameter being specified. The specific values for  $X_{TC}$  are for further study.

NOTE – The details on TC are for further study.

## A.5 Slave clocks

A simplified depiction of the time error generation in a telecom (time) slave clock is shown in Figure A.5-1 below.  $T_{SLV}$  represents the time delivered by the upstream master to reference point U and  $T_{OUT}$  represents the time delivered by the T-TSC to the application.



**Figure A.5-1 – Time error generation components in a slave clock**

The telecom slave clock receives its reference from an upstream master clock. The internal system time of the T-TSC,  $T_{SC}$ , is generally available to an external application via a 1PPS (and ToD) interface or equivalent. There may be uncertainty in this output due to the  $TE_{1PPS}$  term. The interface port of the T-TSC generates time stamps associated with the time-of-arrival of *SYNC* packets ( $T_2$ ) and time-of-departure of *DELAY\_REQUEST* packets ( $T_3$ ). These time stamps are not available externally and there is noise generation associated with each of time stamps,  $TE_2$  and  $TE_3$ , respectively. Denote the time error of the slave clock, with respect to the input reference plane, by  $TE_{SC}$ . Note that this composite time error comprises time-stamp error as well as error components resulting from, for

example, local oscillator (LO) and unfiltered PDV (dynamic time error) present in the reference input. The local oscillator function may include a physical layer assist (e.g., SyncE).

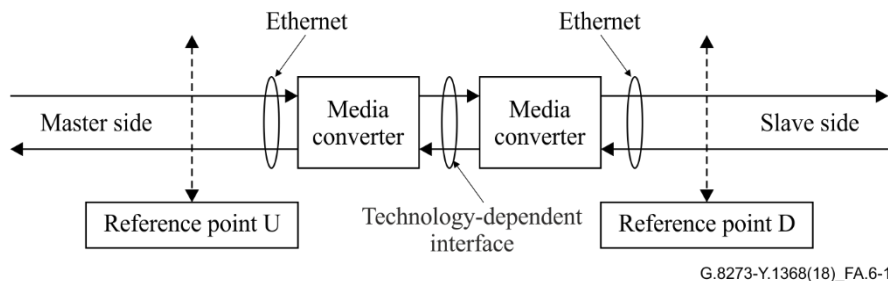
The figure considers only time errors. If the T-TSC also provides a frequency output, that output can be measured against the reference provided to the grandmaster. The frequency output measurement can provide information of slave clock wander at observation intervals less than 1s and slave clock jitter, both unavailable via the 1PPS. The configuration for this is addressed in Annex B.

Assuming that the input reference plane (reference point U) has symmetric or calibrated delays between the plane and the T-TSC input port, a test system can provide an accurate time input or a monitoring device placed there can establish the correct value for  $T_{SLV}$ . The effective time error generation in the slave clock,  $TE_{SC}$ , can be measured by comparing  $T_{SLV}$  and the 1PPS output of the T-TSC. The acceptable limits for time error generation of a slave clock are application dependent and are for further study.

The performance of the slave clock may be verified by observing  $T_3$  at the input reference plane U that is a calibrated (time) distance from the slave port. This requires the slave clock to populate the  $T_3$  time-stamp field with the precise time stamp for time-of-departure, with respect to the slave clock of the *DELAY\_REQUEST* message. Providing the precise value for  $T_3$  in a subsequent message is for further study.

## A.6 Clocks containing media converters

Some clocks may use alternative physical layer technology to inter-connect to the next clock in the chain. For example, the input may be Ethernet and the output may be microwave. To simplify the measurement of these devices, the performance can be measured as a back-to-back pair, such that the measurement reference points are the Ethernet interface of the first media converter, and the Ethernet output port of the second device (as shown in Figure A.6-1). It may also be possible to measure a chain of such devices in the same way.



**Figure A.6-1 – Demarcation of measurement points for testing media converter nodes**

The appropriate budget allocation for a back-to-back pair, or for a chain of such devices, is for further study and will be described in the relevant clock specification.

## Annex B

### Phase/time clock equipment specification related measurement methods

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

#### B.1 Overview

The performance of packet-based phase/time equipment may be measured either by active or passive techniques. With the active technique, a packet-based test device actively participates in the packet exchanges, and performs measurements at the same time as it transmits and receives the timing packets. In this way, the test device acts as a source or sink of timing information. With the passive technique, a packet-based test device monitors packet exchanges over a communication link. In this way, the test device acts as an observer and it does not directly participate in the packet timing protocol.

Annex A provides a basis for the testing methodology and explains what is measured and how to interpret the measurements.

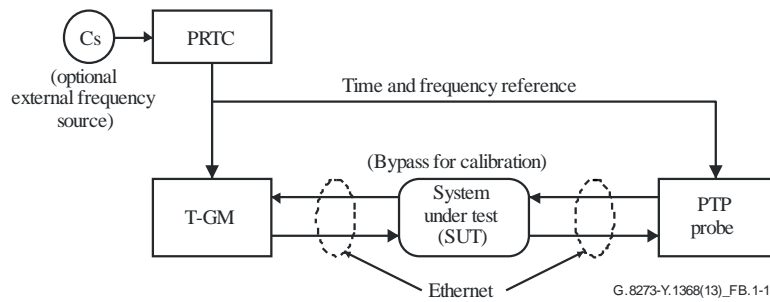
General recommendations for the test system:

- a) A common time/phase reference (e.g., 1PPS) must be used for all elements of the test system. An ARB (arbitrary) timescale is sufficient and can be generated using a PRTC steered by an external frequency. This circumvents any extraneous influences such as GNSS receiver noise.
- b) The timing source must be very stable. This can be achieved using an external frequency source (e.g., caesium (Cs) or other primary reference clock (PRC)-equivalent) that provides very accurate and stable timing (frequency).
- c) Bypassing the SUT provides a baseline test for calibration.
- d) Cabling between units should be done carefully with attention paid to symmetry of delay.
- e) The test system must provide the SUT with a synchronous Ethernet reference if the SUT utilizes the synchronous Ethernet physical layer clock.
- f) The equipment providing the PTP impair function supports synchronous Ethernet in those cases where the SUT utilizes the synchronous Ethernet (i.e., physical layer) as a frequency-assist mechanism, and which further has the ability to introduce physical layer impairments (e.g., wander and frequency offset).
- g) When the SUT does not utilize the physical layer for frequency transfer, testing may be performed to prove independence of frequency recovery in the SUT from the physical layer (e.g., apply wander or offset to the physical layer to validate independence).
- h) External traffic generation is required to introduce suitable loading of the SUT ports including, but not limited to, the ports carrying the timing packets.
- i) It is expected that for the type of measurements implied by the ITU-T G.8273.x series of Recommendations it should always be possible to identify a stable, consistent observation interval when performing a constant time error (cTE) measurement. In general a value of 1000 seconds or greater is recommended.

The test arrangements shown are for the baseline timing performance of the SUT and items related to the PTP protocol are not covered.

#### B.1.1 General active measurement method

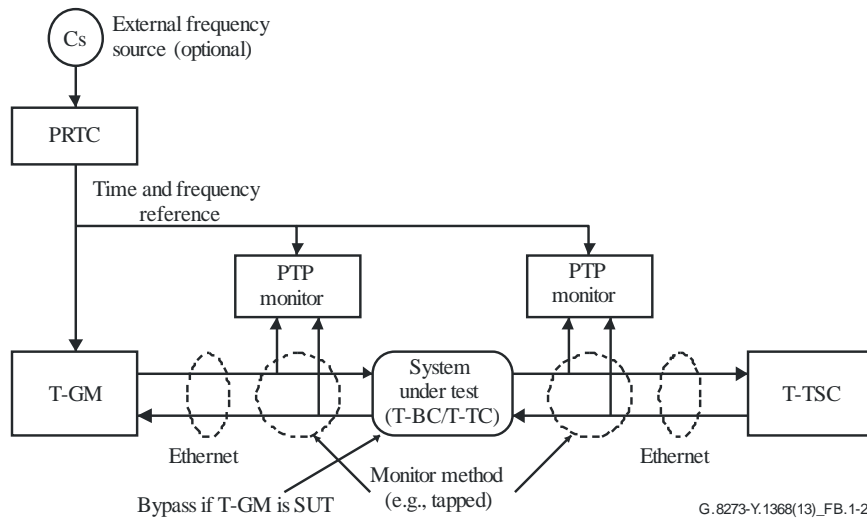
One method to verify the output quality of packet clocks according to the ITU-T G.8273.x-series of Recommendations includes active PTP probes as defined in clause 3.1 of [ITU-T G.8260].



**Figure B.1-1 – Active measurement set-up for systems with PTP time transfer**

### B.1.2 General passive measurement method

A second method to verify the output quality of packet clocks according to the ITU-T G.8273.x series of Recommendations utilizes passive PTP monitors. Figure B.1-2 addresses testing transfer characteristics such as for a T-BC or T-TC. Bypassing the T-BC provides a means for testing the T-GM and in that case only a single PTP monitor block is required.

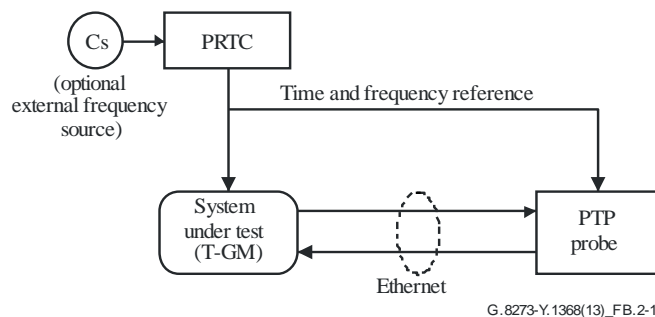


**Figure B.1-2 – Passive measurement set-up for systems with PTP time transfer**

## B.2 Telecom grandmaster test

### B.2.1 Active measurement set-up for testing grandmaster function

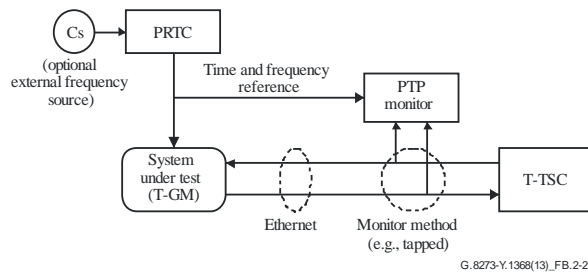
Figure B.2-1 shows a measurement set-up for T-GM clocks using the active approach.



**Figure B.2-1 – Active measurement set-up for (PTP) telecom grandmaster**

### B.2.2 Passive measurement set-up for testing grandmaster function

Figure B.2-2 shows a measurement set-up for T-GM clocks using the passive approach.

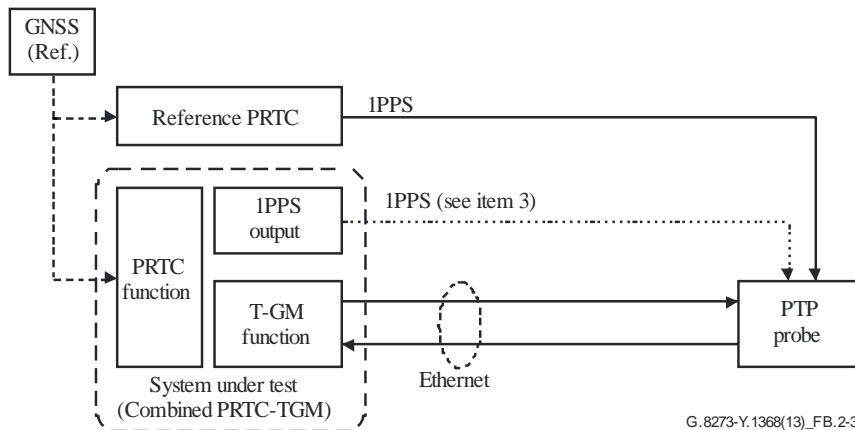


**Figure B.2-2 – Passive measurement set-up for (PTP) telecom grandmaster**

The T-TSC may be replaced by an aggregation of slave clocks either physically or logically in order to simulate the condition of multiple slaves communicating with the GM.

### B.2.3 Active measurement set-up for testing a combined PRTC and grandmaster function

Figure B.2-3 shows a measurement set-up for using the active approach when the PRTC and T-GM are combined into the same physical equipment.



**Figure B.2-3 – Active measurement set-up for a combined "PRTC + T-GM"**

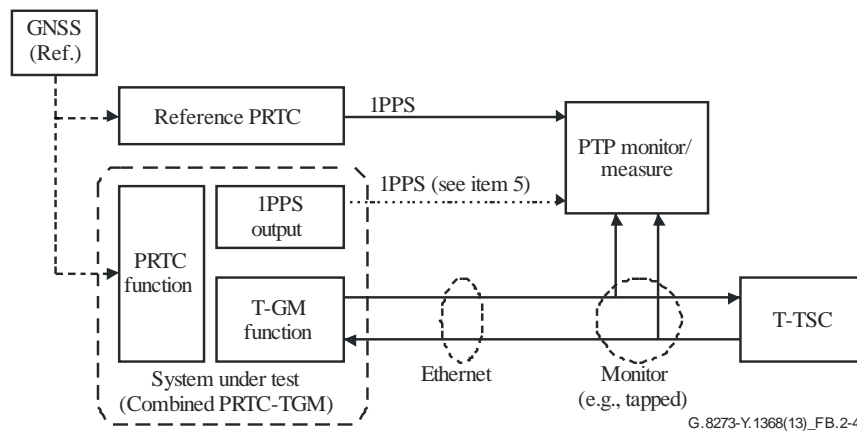
With respect to the arrangement shown:

- 1) As the SUT contains both the PRTC function and the T-GM function, the internal interfaces are vendor-specific. Providing a 1PPS output permits equipment testing and verification.
- 2) The SUT PRTC, as well as the reference PRTC are provided with the same reference input. In this figure, it is assumed that a GNSS (e.g., global positioning system (GPS)) antenna feeds both PRTC instantiations over calibrated cable.
- 3) The reference PRTC is used to measure the time error. Measurement of wander is done using a PRC or equivalent. If the PTP probe cannot measure 1PPS time error then refer to Appendix I of [ITU-T G.8272] for alternative configurations.
- 4) Appendix I of [ITU-T G.8272] provides methods for measuring the wander of the timing output(s) of the unit under test.

NOTE – For configurations suitable for the 'reference PRTC' function, please follow the options according to Appendix I of [ITU-T G.8272].

### B.2.4 Passive measurement set-up for testing a combined PRTC and grandmaster function

Figure B.2-4 shows a measurement set-up for using the passive approach when the PRTC and T-GM are combined into the same physical equipment.



**Figure B.2-4 – Passive measurement set-up for a combined "PRTC + T-GM"**

With respect to the arrangement shown:

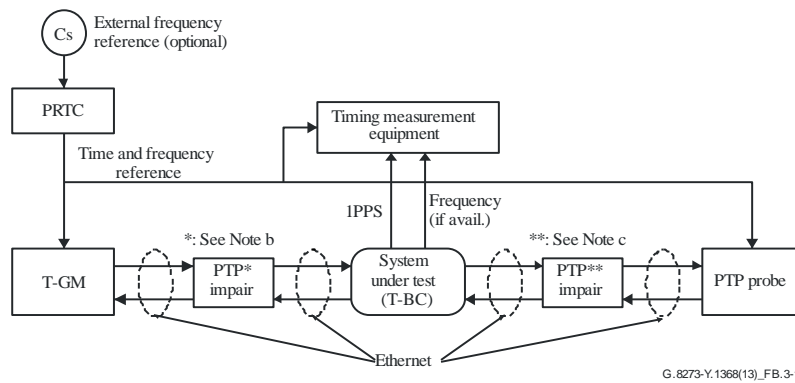
- 1) As the equipment under test contains both the PRTC function and the T-GM function, the internal interfaces are vendor-specific. Providing a 1PPS output permits equipment testing and verification.
- 2) In the tapped monitor method the telecom slave can be connected via a network; the monitor points remain at a calibrated distance from the master port of the SUT.
- 3) The SUT PRTC, as well as the reference PRTC are provided with the same reference input. In this figure it is assumed that a GNSS (e.g., GPS) antenna feeds both PRTC instantiations over calibrated cable.
- 4) The T-TSC may be replaced by an aggregation of slave clocks either physically or logically in order to simulate the condition of multiple slaves communicating with the T-GM.
- 5) The reference PRTC is used to measure the time error. Measurement of wander is done using a PRC or equivalent. If the PTP monitor/measure system cannot measure 1PPS time error then refer to Appendix I of [ITU-T G.8272] for alternative configurations.
- 6) Appendix I of [ITU-T G.8272] provides alternative methods for measuring the wander of the timing output(s) of the unit under test.

NOTE – For configurations suitable for the 'reference PRTC' function, please follow the options according to Appendix I of [ITU-T G.8272].

### **B.3 Telecom boundary clock test**

#### **B.3.1 Active measurement set-up for systems with telecom boundary clocks**

Figure B.3-1 shows an active measurement set-up for a T-BC. Active PTP probe measurement, as well as 1PPS time error measurement is recommended to be performed at the same time.



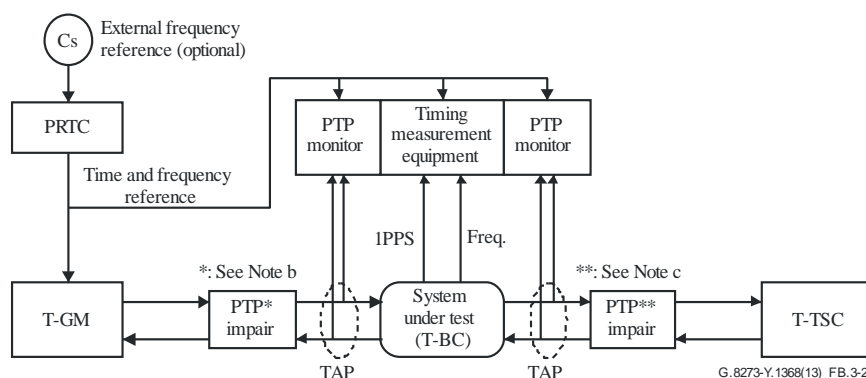
**Figure B.3-1 – Active measurement set-up for systems with T-BC**

With respect to the test arrangement shown:

- The 'Time Reference' 1PPS output is used as reference for time error measurement of the T-BC 1PPS output.
- One PTP impair function is used to emulate network impairments between the SUT and the GM in order to perform stress testing, where necessary, of the slave side of the T-BC.
- One PTP and SyncE impair function is used to emulate network impairments between the SUT and the downstream slave in order to perform stress testing, where necessary, of the master side of the T-BC.
- Suitable means are provided for injecting interfering traffic to mimic network loading conditions. The non-PTP traffic is also included on the ports carrying PTP packets for both master and slave ports of the T-BC.
- For SUTs that provide frequency outputs, these are measured against the reference.

### B.3.2 Passive measurement set-up for systems with telecom boundary clocks

Figure B.3-2 shows a passive set-up for the measurement of the performance of a T-BC. In this case, the packets between the upstream PTP source and the downstream PTP termination device are monitored concurrently in order to measure the ability of the SUT to transfer time in the packet domain.



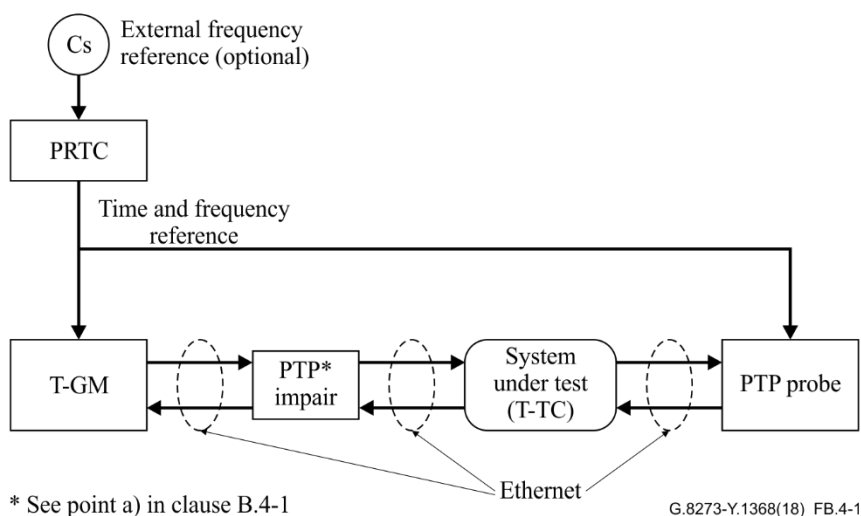
**Figure B.3-2 – Passive measurement set-up for systems with T-BC**

The statements regarding the test arrangement provided in clause B.3.1 for the active measurement set-up apply to the passive measurement set-up shown in Figure B.3-2.

## B.4 Measurement set-up for systems with transparent clocks

### B.4.1 Active measurement set-up for systems with telecom transparent clocks

Figure B.4-1 shows an active measurement set-up for a T-TC.



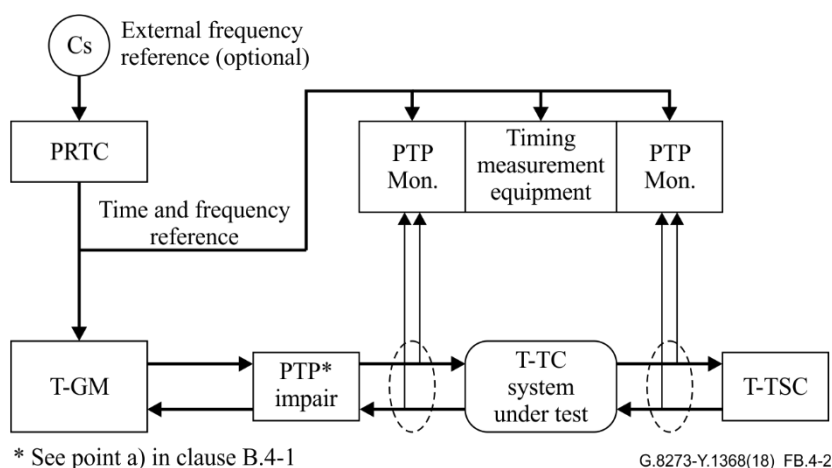
**Figure B.4-1 – Active measurement set-up for systems with T-TC**

With respect to the test arrangement shown:

- One PTP impair function is used to emulate network impairments between the SUT and the GM in order to perform stress testing, where necessary, of the PEC function of the T-TC.
- Suitable means are provided for injecting interfering traffic to mimic network loading conditions. The non-PTP traffic loading must include the ports carrying the PTP traffic.
- When calculating the T-TC noise generation and noise transfer using the above set-up, the PTP impairment must be known and compared with the PTP probe measurements.

### B.4.2 Passive measurement set-up for systems with telecom transparent clocks

Figure B.4-2 shows a passive measurement set-up for a T-TC.

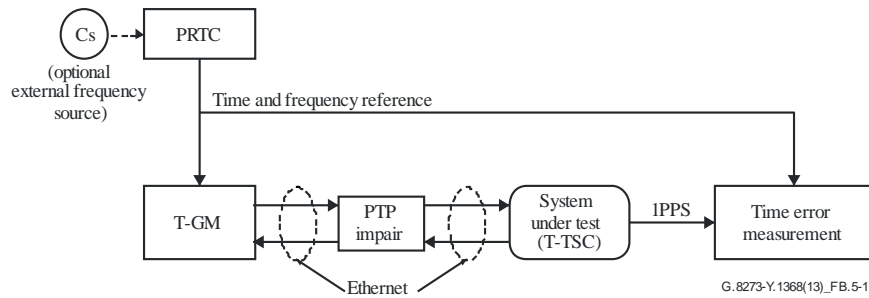


**Figure B.4-2 – Measurement set-up for systems with T-TC**

The statements regarding the test arrangement provided in clause B.4.1 for the active measurement set-up apply to the passive measurement set-up shown in Figure B.4-2.

## B.5 Measurement set-up for systems with telecom time slave clock

Figure B.5-1 shows an appropriate measurement set-up for T-TSC.



**Figure B.5-1 – Measurement set-up for systems with T-TSC**

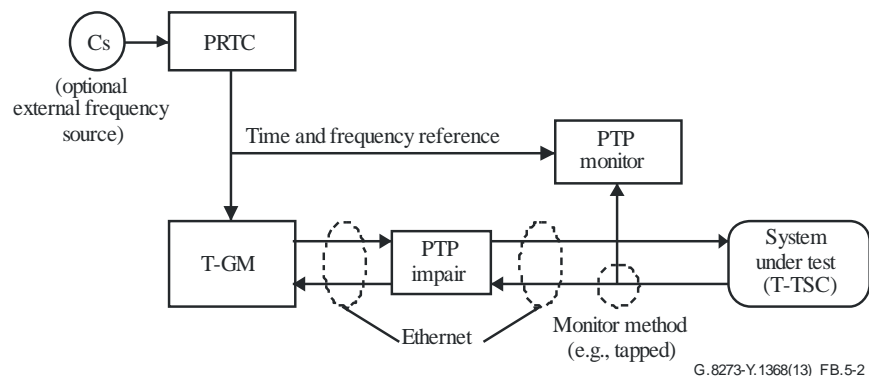
With respect to the test arrangement shown:

- The PTP impair function is used to emulate network impairments in order to perform stress testing where necessary. Alternatively, other arrangements for introducing interfering traffic are possible.
- The equipment providing the PTP impair function supports synchronous Ethernet in those cases where the T-TSC utilizes the synchronous Ethernet (i.e., physical layer) as a frequency-assist mechanism and has the ability to introduce physical layer impairments (e.g., wander and frequency offset).

[IEEE 1588-2008] does not require a slave to send an accurate T3 time stamp. However, if the slave provides an accurate T3 time stamp, the performance of the slave clock may be evaluated by observing the embedded time stamp T3 representing the time-of-departure of the *DELAY\_REQUEST* message, with respect to the slave clock. A suitable configuration is depicted in Figure B.5-2. Such an approach permits testing the T-TSC even when the T-TSC does not provide a physical 1PPS output signal, for example, when the T-TSC is integrated into the network element.

The accuracy of this measurement is dependent on the accuracy of the time stamp ( $T_3$ ) embedded in the *DELAY\_REQUEST* message and the calibration of the delay between the tap and the slave port.

Figure B.5-2 shows the measurement set-up for evaluating T-TSC performance using the packet timing signal.



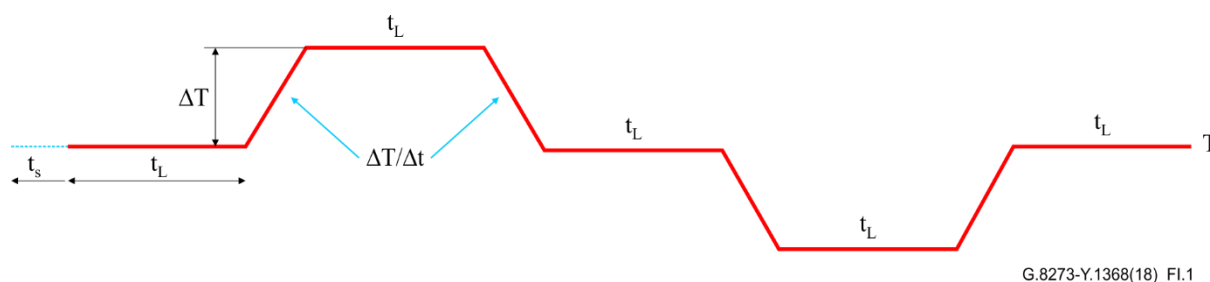
**Figure B.5-2 – Measurement set-up for systems with T-TSC based on packet timing signal**

## Appendix I

### Variable temperature testing methodology

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

Where variable temperature testing is required, it should be conducted using the temperature profile shown in Figure I.1.



**Figure I.1 – Temperature profile**

The test should be repeated at different test reference temperatures,  $T$ , to cover the required temperature range. As a minimum the tests should be performed at nominal and temperature extremes, i.e., the reference temperature  $T$  set to  $T_{\min} + \Delta T$ ,  $T_{\text{nom}}$  and  $T_{\max} - \Delta T$ .

The test stabilisation time  $t_s$  should be long enough to remove start-up effects. The loop recovery time  $t_L$  is dictated by the loop time constant and should be as a minimum three times the loop time constant to allow the loop to recover.

The constrained temperature excursion  $\Delta T$  and the ramp rate  $\Delta T/\Delta t$  should be aligned to the environmental profile.

As an example, the constrained temperature excursion  $\Delta T$  could be set to 20°C and the ramp rate  $\Delta T/\Delta t$  to 0.5°C/minute, if these are the applicable environmental conditions.

An additional consideration is the abruptness of the transition between ramping and constant temperature conditions. The second derivative of temperature versus time that occurs at such transitions is relevant for properties such as the oscillator thermal control and system loop responses. If these transitions are applied too rapidly, it could cause unrealistic environmental conditions. The rate of change between ramping temperature and stable temperature conditions is for further study.

## Appendix II

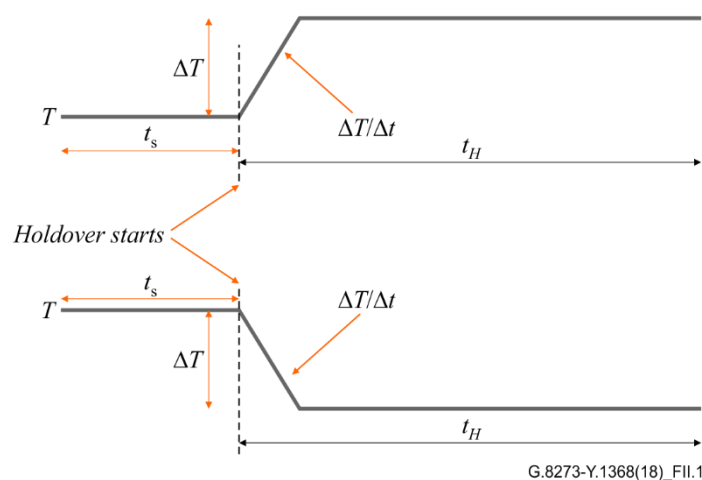
### Variable temperature holdover testing methodology

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

Appendix I describes temperature profile for generic variable temperature testing. This appendix describes details for variable temperature holdover testing methodology.

For testing holdover, the duration of the test should correspond to the duration of the holdover period. The worst-case pattern is a temperature change that takes effect during the holdover period.

Figure II.1 depicts negative and positive slope cases. Various starting temperatures would be used to cover the operating temperature range.



**Figure II.1 – Variable temperature profile for holdover testing**

The test should be repeated at different test reference temperatures  $T$ , to cover the required temperature range. At a minimum the tests should be performed at nominal and temperature extremes, i.e., the reference temperature  $T$  set to  $T_{\min} + \Delta T$ ,  $T_{\text{nom}}$  and  $T_{\max} - \Delta T$ .

The test stabilisation time of  $t_s$  period should be long enough to remove start-up effects while  $t_H$  equates to the duration of the test for the corresponding period of the required holdover duration. The worst-case pattern is a temperature change that remains during the holdover period.

The constrained temperature excursion  $\Delta T$  and the ramp rate  $\Delta T/\Delta t$  should be aligned to the environmental profile.

As an example, the constrained temperature excursion  $\Delta T$  could be set to 20°C and the ramp rate  $\Delta T/\Delta t$  to 0.5C/minute, if these are the applicable environmental conditions.

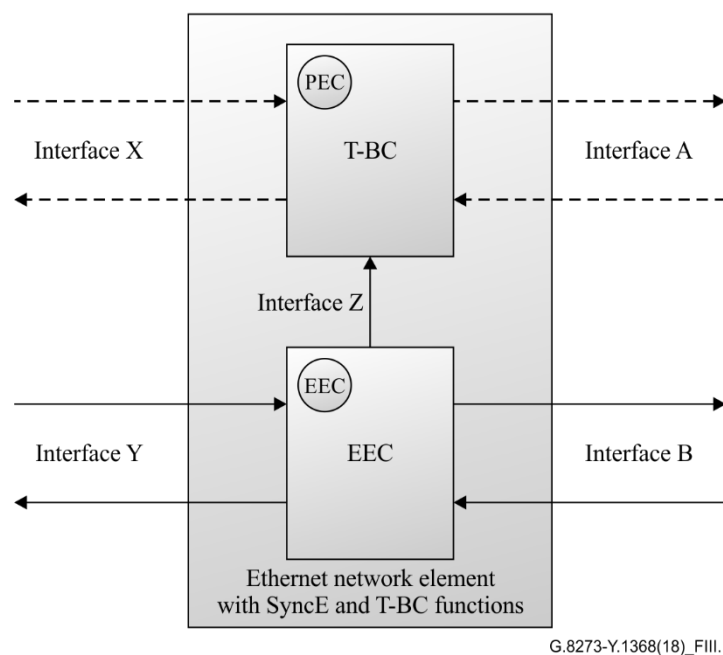
## Appendix III

### Synchronous Ethernet transient testing methodology

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

This appendix addresses the test method to measure the effects of a SyncE transient being received from an upstream T-BC. The output signal is measured without a measurement filter. The timing of events in each of the test methods should be accurate to within  $\pm 1\%$ .

A model for the T-BC is shown in Figure III.1; this does not imply any implementation.



G.8273-Y.1368(18)\_FIII.1

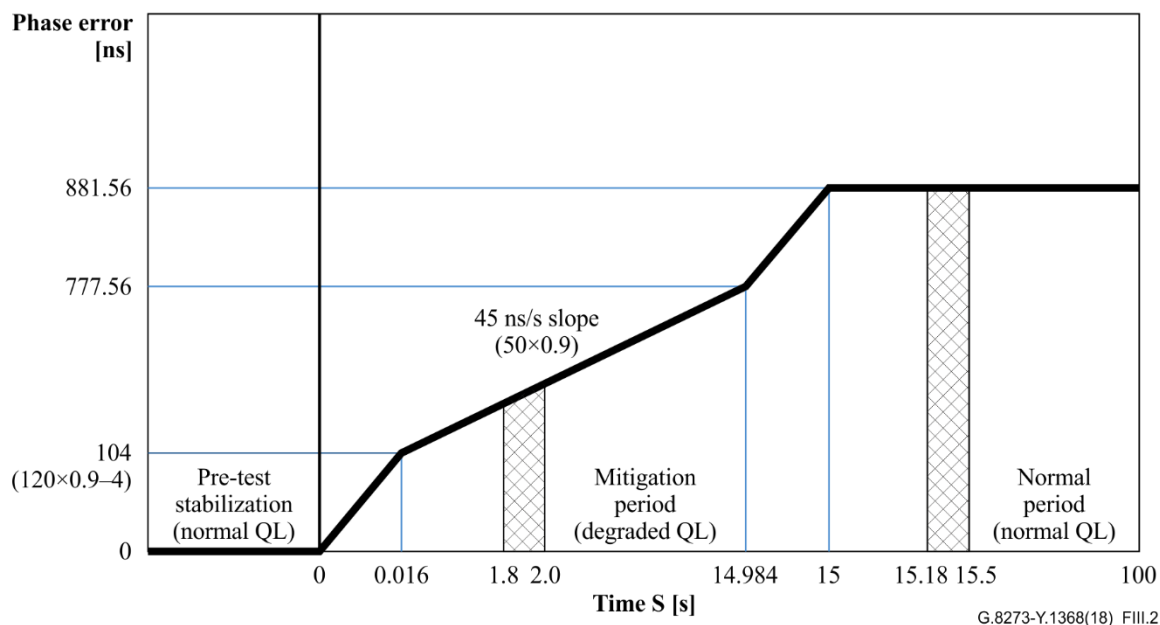
**Figure III.1 – Example NE with EEC and T-BC functions**

For all test methods, the output performance is described in the relevant clock specification. For example, in the case of a T-BC, it is described in Annex B of [ITU-T G.8273.2].

#### Method 1 steps

- 1) Input an ideal SyncE signal with quality level (QL)-PRC at interface Y and an ideal IEEE 1588 signal at interface X;
- 2) Wait for the T-BC to be fully stabilized;
- 3) Start the SyncE transient input signal pattern (e.g., ITU-T G.8262 transient noise) at interface Y, and send Ethernet synchronization message channel (ESMC) with QL-EEC at interface Y between 1800 ms and 2000 ms after the start of the transient based on the time of holdover message of [b-ITU-T G.781];
- 4) Wait until 15 seconds (the longest duration before the second transient) after the start of the SyncE transient;
- 5) Send ESMC with QL restored to QL-PRC at interface Y after the 15 second mark of step 4, between 180 ms and 500 ms based on the time of the switching message of [b-ITU-T G.781];
- 6) Wait 85 seconds and end the test.

The SyncE transient input signal pattern is shown in Figure III.2.



**Figure III.2 – Method 1 SyncE Transient Input Pattern**

#### Method 2 steps

- 1) Input an ideal SyncE signal with QL-PRC at interface Y and an ideal IEEE 1588 signal at interface X;
- 2) Wait for the T-BC to be fully stabilized;
- 3) Disconnect the input SyncE link at interface Y;  
NOTE 1 – Disconnecting the SyncE link can be accomplished by several methods (e.g., disconnecting the cable, disabling the port).
- 4) After 15 seconds, restore the input SyncE link at interface Y;
- 5) Wait 85 seconds and end the test.

NOTE 2 – This test may not be applicable or possible in all circumstances. For example, if the SyncE and PTP messages are provided via a common physical port, the SyncE cannot be disconnected without also disconnecting the PTP.

#### Method 3 steps

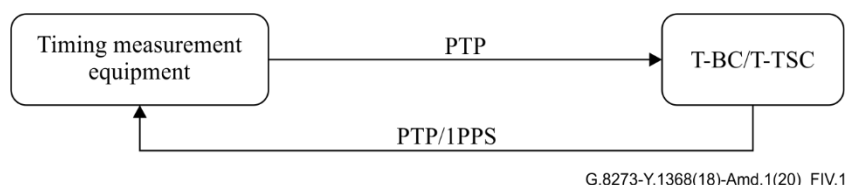
- 1) Input an ideal SyncE signal with QL-PRC at interface Y and an ideal IEEE 1588 signal at Interface X;
- 2) Wait for the T-BC to be fully stabilized;
- 3) Input ESMC with QL degraded to QL-EEC at interface Y;
- 4) After 15 seconds, restore the input ESMC with QL restored to QL-PRC at interface Y;
- 5) Wait 85 seconds and end the test.

## Appendix IV

### Measurement of noise transfer using least squares method

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

The noise transfer test installation is shown in Figure IV.1; the nominal value of the PTP packet rate is 16 packets/s, and the packet rate of 1PPS can be considered as 1 packet/s.



**Figure IV.1 – T BC/T-TSC noise transfer test installation**

The frequency signal generated inside the installation, both from measurement device and T-BC/T-TSC, is noted as,

$$y(t) = A \cos(2\pi f t - \psi) \quad (\text{IV.1})$$

The signal of single frequency  $f$  is sampled at sampling frequency  $f_s$ . The sampled series is naturally added with noise cTE and dTE of the T-BC. The sampled series is:

$$y(t_i) = A \cos\left(\frac{2\pi f}{f_s}(f_s t) - \varphi\right) + \text{cTE} + \text{dTE}, \quad (\text{IV.2})$$

where  $t_i$  is the sampling time.

The quantity  $f/f_s$  in Eq. IV.2 should satisfy the Nyquist criterion, i.e.,  $f/f_s < 1/2$ . It is required to have cTE as a pre-known and constant value, and then to subtract cTE from the original sampled series; this produces a new series  $q_i$ , where  $q_i = y(t_i) - \text{cTE}$ . Set  $1/k = f/f_s$ , and note that  $k$  is not necessarily an integer (i.e.,  $f_s$  is not necessarily an integer multiple of  $f$ ). Define  $i = f_s t_i$ , and note that  $i$  is an integer because the samples are taken at integer multiples of the sampling interval, which is  $1/f_s$ . Then Eq. (IV.2) can be written as:

$$q_i = \alpha \cos\left(\frac{2\pi i}{k}\right) + \beta \sin\left(\frac{2\pi i}{k}\right) + n(t_i), \quad (\text{IV.3})$$

where:

$$\alpha = A \cos \varphi$$

$$\beta = A \sin \varphi$$

$i$  = the sample number in the series, with  $0 \leq i \leq N$

$N$  = the total number of samples minus one, and

$N$  and  $i$  are both positive integers.

Even though  $i$  is an integer,  $f_s$  and  $t_i$  are not necessarily integers. To perform linear regression using the least squares method, define the quantity  $Q$

$$Q = a \cos\left(\frac{2\pi}{k} i\right) + b \sin\left(\frac{2\pi}{k} i\right). \quad (\text{IV.4})$$

Set the partial derivatives of  $\Sigma(q_i - Q)$  to zero, i.e.

$$\frac{\partial \left( \sum_{i=1}^N (q_i - Q)^2 \right)}{\partial a} = 0$$

$$\frac{\partial \left( \sum_{i=1}^N (q_i - Q)^2 \right)}{\partial b} = 0$$
(IV.5)

Then

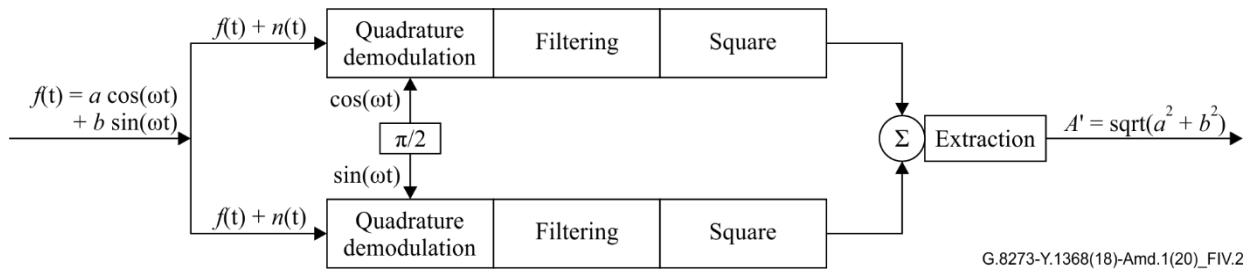
$$\sum_{i=0}^N q_i \cos\left(\frac{2\pi i}{k}\right) = a \sum_{i=0}^N \cos^2\left(\frac{2\pi i}{k}\right) + b \sum_{i=0}^N \sin\left(\frac{2\pi i}{k}\right) \cos\left(\frac{2\pi i}{k}\right)$$
(IV.6)

$$\sum_{i=0}^N q_i \sin\left(\frac{2\pi i}{k}\right) = b \sum_{i=0}^N \sin^2\left(\frac{2\pi i}{k}\right) + a \sum_{i=0}^N \sin\left(\frac{2\pi i}{k}\right) \cos\left(\frac{2\pi i}{k}\right),$$
(IV.7)

The samples 0, 1, 2, ...,  $N$  are acquired during the test period from 0 to  $t_i$ . From Eq. (IV.6) and Eq. (IV.7), the unknown quantities  $a$  and  $b$  can be obtained, and the calculated amplitude  $A'$  of the input frequency is

$$A' = \sqrt{a^2 + b^2}$$
(IV.8)

For a clearer illustration, Eqs. (IV.6) – (IV.8) can be represented by the physical module in Figure IV.2.



**Figure IV.2 – Quadrature balanced demodulation system**

The left parts of Eqs. (IV.6) and (IV.7) are similar to quadrature demodulation as shown in Figure IV.2, the summation "Σ" can be considered as the filtering operation in the figure, and Eq. (IV.8) equals to the final result in Figure IV.2, which is the extraction of the sum of each side's square result.

Figure IV.2 shows a typical quadrature balanced demodulation system plus the operation of square and extraction. The output of interest is not the sinusoid itself, but the amplitude  $A$  of the sinusoid;  $A$  is what is needed for noise transfer test.

It should be noted that in the noise transfer test, each sample contains two types of information, one is the time instant  $t$  of PTP, and the other is the amplitude  $A$  of the input sinusoid. The former is used for PTP processing, and the latter is used in the least squares process. Since each sample conveys the amplitude  $A$  of the input frequency, the least squares method in Figure IV.2 applies the same operation to each sample, which is to add the output of one side of the quadrature signal to the output of the other side, and the result will be the amplitude  $A'$  after taking the square root.

If the device under test is ideal, its noise  $n(t) = 0$ , and the output amplitude series  $\{A'_i\}$  has the constant value  $A$ . If the device under test is not ideal, its noise is  $n(t) \neq 0$ ; then, as the number of sample increases, the variable vector amplitude series  $\{A'_i\}$  accuracy should improve so that when the test

finishes, the last  $A_N$  is the best value. This illustrates the least squares method attribute, where each of the  $N$  samples contributes equally to the result.

The most important parameter of least square method is the total number of samples  $N$ .

The duration used for a given test depends on the accuracy required, the longer the test, the better the accuracy. Two aspects requiring particular attention: in equation (3), cTE needs to be removed before the least squares calculation, and the test duration  $T$  needs to meet  $T > 1/f$ , where  $f$  is the frequency of the input sinusoid.

Note that this method is only applicable for noise generation with white phase modulation. The accuracy of this method when the noise generation has different characteristics (e.g., random walk, other power-law noise types, or sinusoidal noise) is for further study.

## **Bibliography**

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



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