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SERIES G: TRANSMISSION SYSTEMS AND MEDIA,
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Packet over Transport aspects – Quality and availability
targets

SERIES Y: GLOBAL INFORMATION
INFRASTRUCTURE, INTERNET PROTOCOL ASPECTS
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Internet protocol aspects – Transport

Framework of phase and time clocks

Recommendation ITU-T G.8273/Y.1368

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Recommendation ITU-T G.8273/Y.1368

Framework of phase and time clocks

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.

History

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FOREWORD

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Recommendation ITU-T G.8273/Y.1368

Framework of phase and time clocks

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 (2012), *Definitions and terminology for synchronization in packet networks*.
- [ITU-T G.8271] Recommendation ITU-T G.8271/Y.1366 (2012), *Time and phase synchronization aspects of packet networks*.
- [ITU-T G.8271.1] Recommendation ITU-T G.8271.1/Y.1366.1 (2013), *Network limits for time synchronization in packet networks*.
- [ITU-T G.8272] Recommendation ITU-T G.8272/Y.1367 (2012), *Timing characteristics of primary reference time clocks*.
- [ITU-T G.8273.2] Recommendation ITU-T G.8273.2/Y.1368.2 (2014), *Timing characteristics of telecom boundary clocks and telecom time slave clocks*.
- [ITU-T G.8275] Recommendation ITU-T G.8275/Y.1369 (2013), *Architecture and requirements for packet-based time and phase distribution*.
- [IEEE 1588-2008] IEEE 1588-2008, *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
FFO	Fractional Frequency Offset
GM	Grandmaster
MTIE	Maximum Time Interval Error
PPS	Pulse Per Second
PRTC	Primary Reference Time Clock
PTP	Precision Time Protocol
SUT	System Under Test
SyncE	Synchronous Ethernet
T-BC	Telecom Boundary Clock
TDEV	Time Deviation
T-GM	Telecom Grandmaster
ToD	Time of Day
T-TC	Telecom Transparent Clock
T-TSC	Telecom Time Slave Clock

5 Conventions

Within this Recommendation, the following conventions are used: the term 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.

This Recommendation refers to the ITU-T G.8273.x series of Recommendations. At the time of publication of this document, not all the documents within the series had been approved; they were under study. This means that those documents that remain under study are subject to change. Here is the current working list of titles for the ITU-T G.8273.x series of Recommendations:

Recommendation ITU-T G.8273/Y.1368 (2013), *Framework of phase and time clocks*.

Recommendation ITU-T G.8273.1/Y.1368.1 (under study), *Timing characteristics of telecom grandmaster clocks*.

Recommendation ITU-T G.8273.2/Y.1368.2 (2014), *Timing characteristics of telecom boundary clocks and telecom time slave clocks*.

Recommendation ITU-T G.8273.3/Y.1368.3 (under study), *Timing characteristics of telecom transparent clocks*.

Recommendation ITU-T G.8273.4/Y.1368.4 (under study), *Timing characteristics of assisted partial timing support slave clocks*.

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.

Three generic types of clocks, and one associated device, are associated with PTP:

- 1) Grandmaster clocks. The implication here is that the clock is a "master" clock and it receives its timing reference (frequency as well as phase/time) by methods other than packet-based methods.
- 2) Boundary clocks. The implication here is the clock has an "output", namely a master clock side and receives its timing reference via PTP from an upstream master clock (either a grandmaster or another boundary clock). That is, the boundary clock has an "input", namely a slave clock side and internally transfers time/phase to its master side. A boundary clock provides an auxiliary output (i.e., 1PPS) that reflects the performance of the slave side. A boundary clock may have an auxiliary input to extract a frequency reference (e.g., synchronous Ethernet).
- 3) Transparent clocks. Transparent clocks are devices (network elements) that modify the content of PTP packets, permitting the PTP "source" and PTP "destination" to factor out the delay introduced by the device. Strictly speaking a "transparent clock" is not a clock but a means for providing on-path support for packet-based timing based on PTP.
- 4) Slave clocks. The implication is that the clock has an "input" that is packet-based from where it extracts its timing reference (time/phase). The output can be of various formats (e.g., 1PPS), generally not packet-based. A slave clock may have an auxiliary input to extract a frequency reference (e.g., synchronous Ethernet).

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

The ITU-T G.8273.x series of Recommendations are expected to define the following; however, it is important to note that as of the date of publication, not all documents mentioned have been approved yet and 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 in Amendment 1 of [ITU-T G.8272]. Other types of T-GM are for further study and are expected to be specified in Recommendation ITU-T G.8273.1/Y.1368.1 (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. The details of T-TC are for further study and are expected to be specified in Recommendation ITU-T G.8273.1/Y.1368.1 (currently under study).
- 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.
- The assisted partial timing support slave clock (APTSC). The details of APTSC are for further study and are expected to be specified in Recommendation ITU-T G.8273.4/Y.1368.4 (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 MTIE (maximum time interval error) and TDEV (time deviation). 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 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:

- a) Associated with the *SYNC* message:
 - 1) T_1 : Time-of-departure from master port.
 - 2) T_2 : Time-of-arrival at slave port.
- b) 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 two-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.

Note that 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 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.

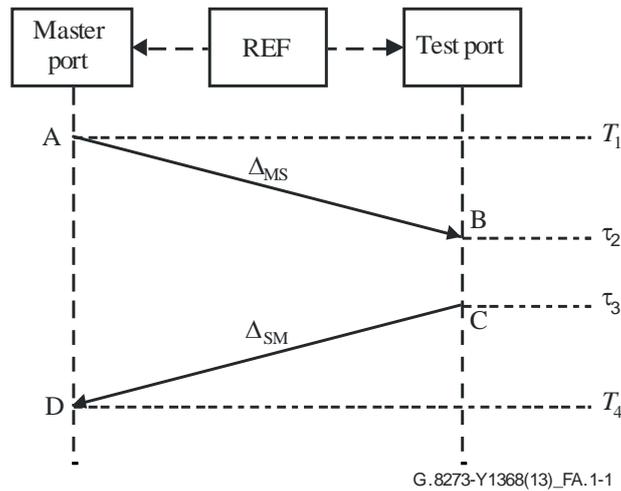


Figure A.1-1 – Depicting the situation where the system under test (SUT) is connected to a test device and PTP messages are exchanged

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 τ_2 . The estimate of the forward transmission delay, Δ_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 τ_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, Δ_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 Δ_{MS} and Δ_{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 Δ , 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 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

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

where the notation $\langle \rangle$ is used for the constant time error estimation and $X_{CONSTANT}$ 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 $X_{CONSTANT}$ 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.

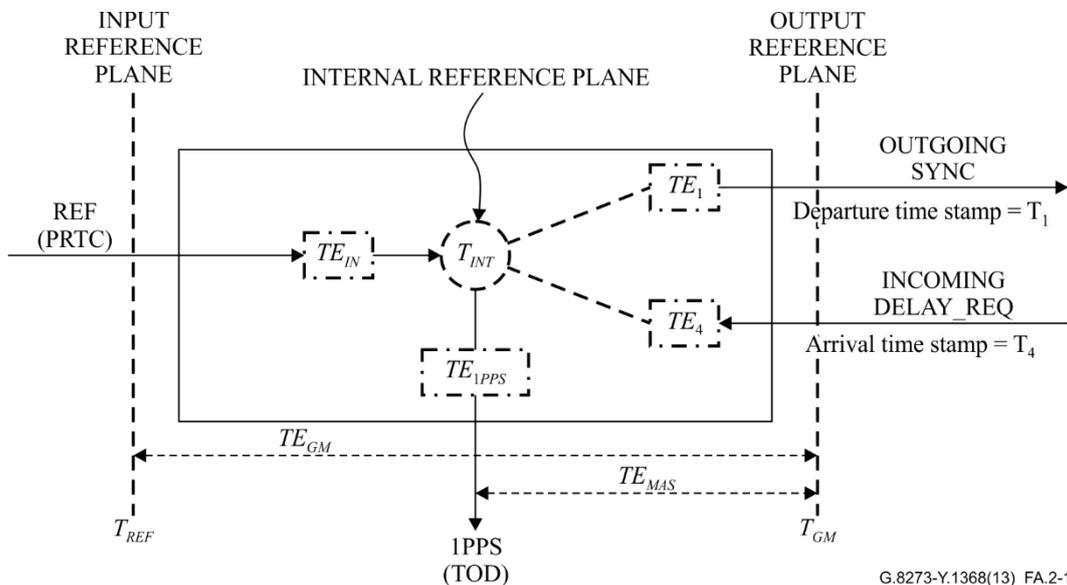


Figure A.2-1 – Noise generation model for a grandmaster clock

A grandmaster clock receives its reference from a PRTC or, in the event that the T-GM and PRTC are combined, the reference may come from other sources such as a GNSS receiver. The internal master time of the T-GM, T_{GM} , is available via a 1PPS (and 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

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

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 τ_2 and τ_3 and observes T_1 and T_4 (refer to Figure A.2-2 for definition of τ_2 and τ_3). Denoting the (symmetric) cable delay by Δ , the time error components TE_1 and TE_4 are computed as

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

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 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:

- constant time error, and
- 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

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

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 $\frac{|(TE_1(n))+(TE_4(m))|}{2}$ 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 Δ_{MS} and the reverse direction by Δ_{SM} . The quantity ε represents the time-offset between the SUT (GM) and the test device.

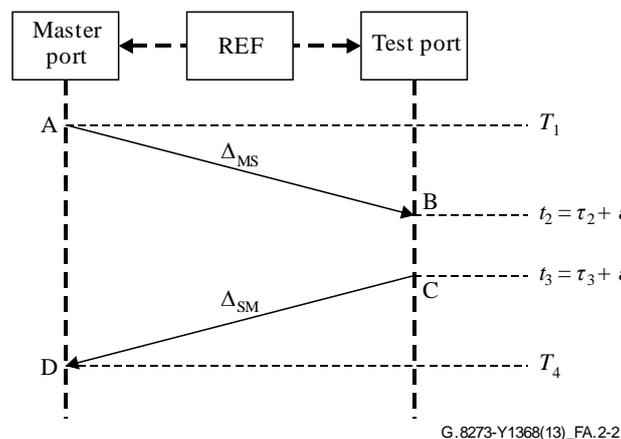


Figure A.2-2 – Depicting the situation where the SUT is connected to test device and PTP messages are exchanged

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 τ_2 . The equivalent time at the master is t_2 , given by

$$t_2 = \tau_2 + \varepsilon \tag{A.2.5}$$

The test device sends a *DELAY_REQUEST* packet at "C" and the time-of-departure noted as τ_3 and the equivalent time at the master, t_3 , is given by

$$t_3 = \tau_3 + \varepsilon \tag{A.2.6}$$

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 Δ_{MS} and Δ_{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

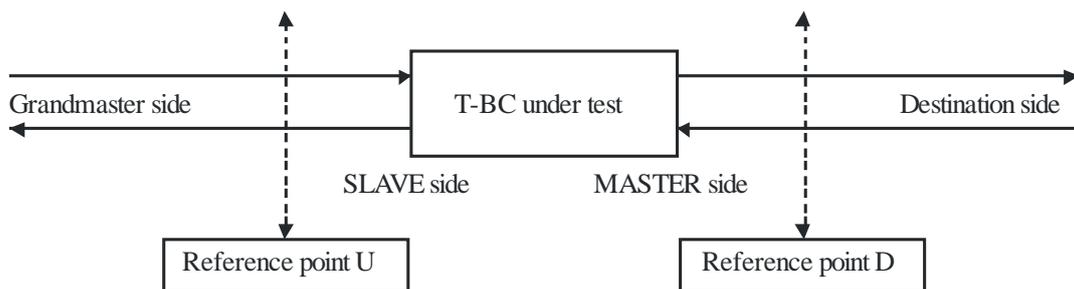
$$\begin{aligned} |T_1[n] - T_{1REF}[n]| &< Y_1 \\ |T_4[m] - T_{4REF}[m]| &< Y_4 \end{aligned} \quad (\text{A.2.9})$$

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.

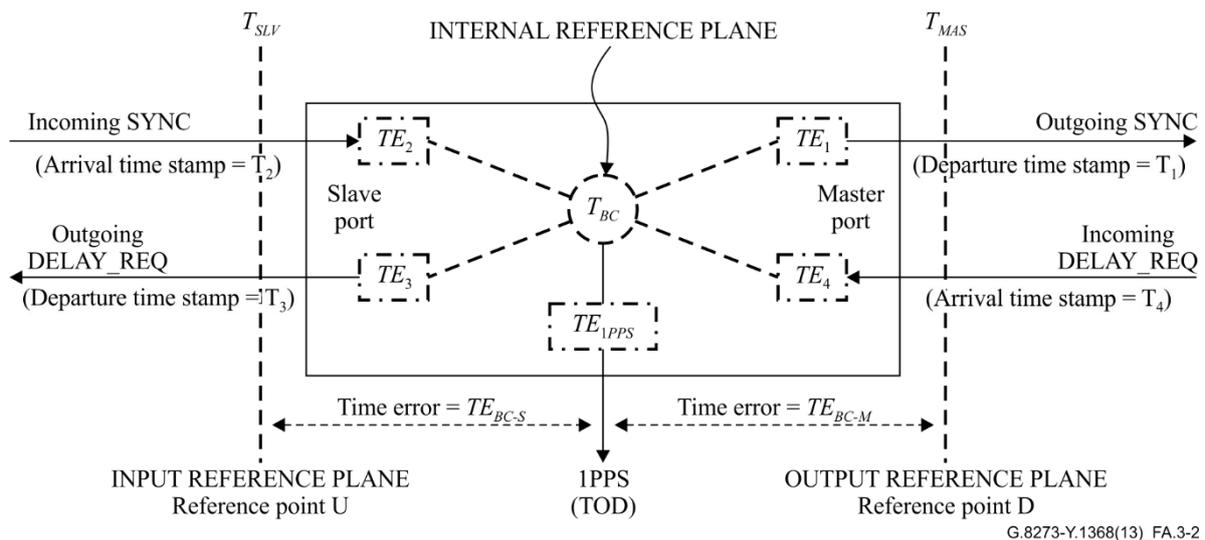


Figure A.3-2 – Time error generation components in a boundary clock

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

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

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 τ_2 and τ_3 and observes T_1 and T_4 (see Figure A.2-2 in clause A.2). Denoting the (symmetric) cable delay by Δ , the time error components TE_1 and TE_4 are computed as

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

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 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

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

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]. This is achieved by adjusting the *correction_field* by an amount equal to the residence time.

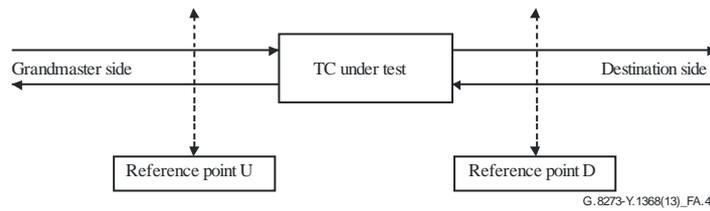


Figure A.4 – Demarcation of measurement points for testing TC performance

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.

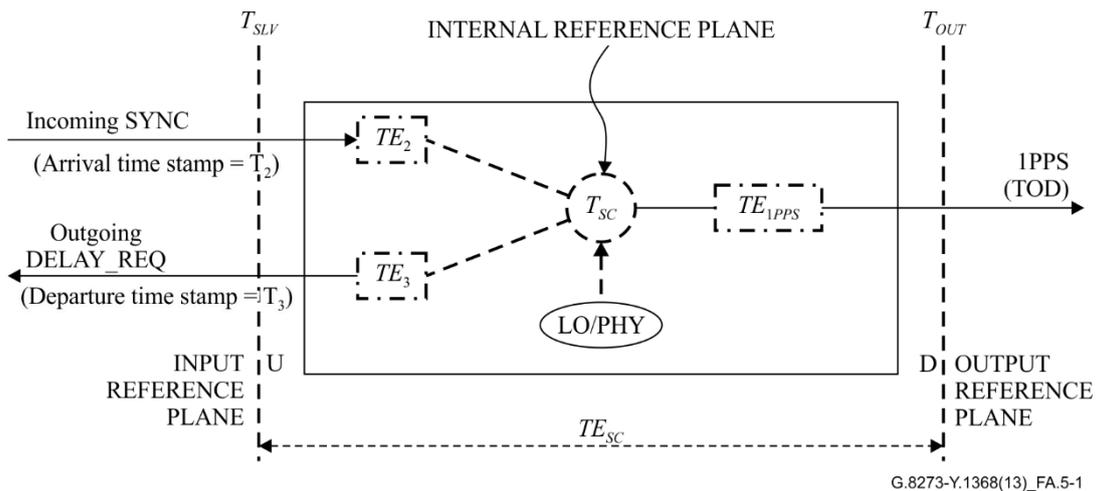


Figure A.5-1 – Time error generation components in a slave clock

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.

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 or other PRC-equivalent) that provides very accurate and stable timing (frequency).
- c) Bypassing the system under test 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 system under test (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 cTE measurement. In general a value of 1000 s 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].

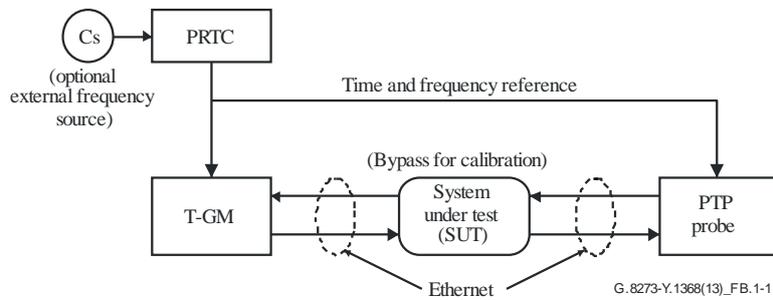


Figure B.1-1 – Active measurement set-up for systems with PTP time transfer

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.

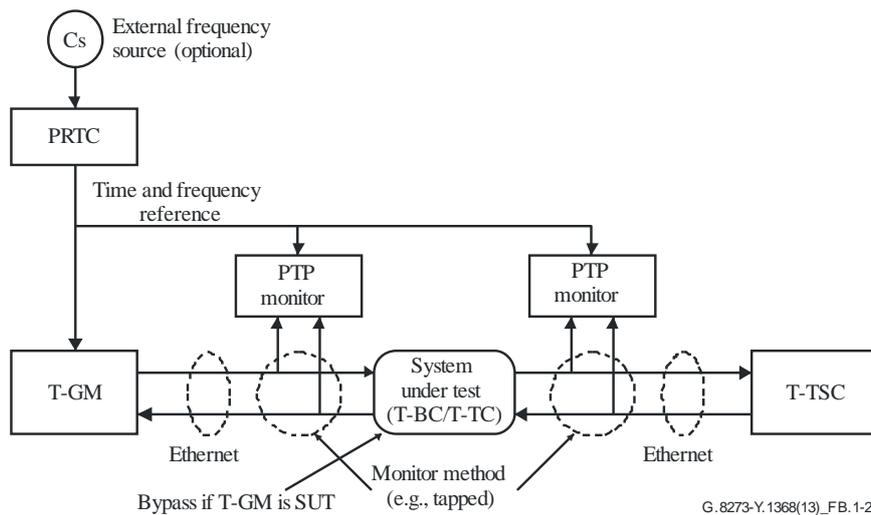


Figure B.1-2 – Passive measurement set-up for systems with PTP time transfer

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 telecom grandmaster (T-GM) clocks using the active approach.

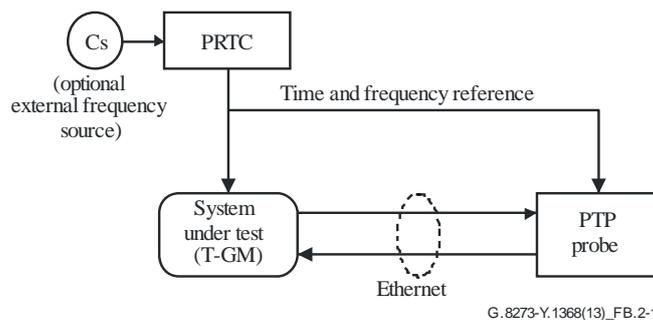


Figure B.2-1 – Active measurement set-up for (PTP) telecom grandmaster

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

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

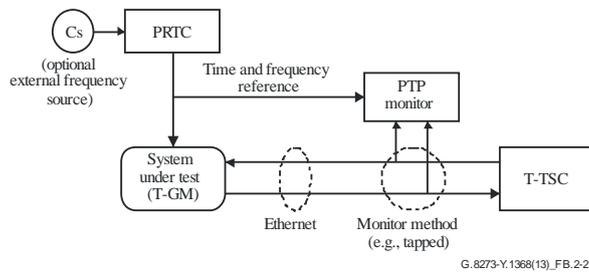


Figure B.2-2 – Passive measurement set-up for (PTP) telecom grandmaster

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.

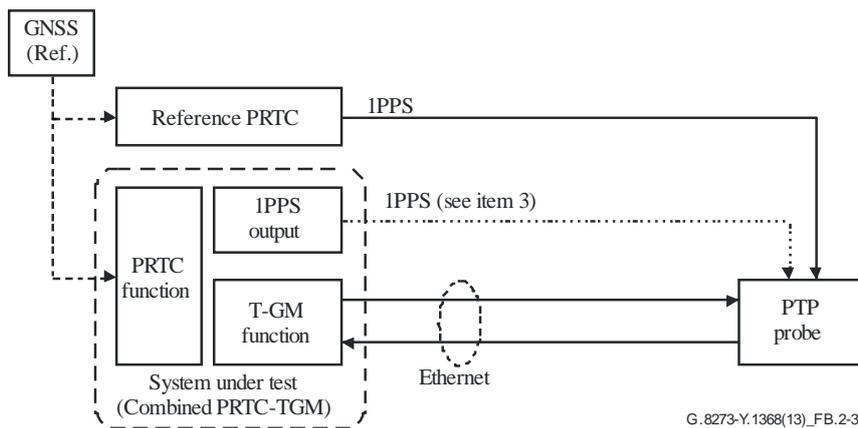


Figure B.2-3 – Active measurement set-up for a combined "PRTC + T-GM"

With respect to the arrangement shown:

- 1) As the system 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) The system under test 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.
- 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.

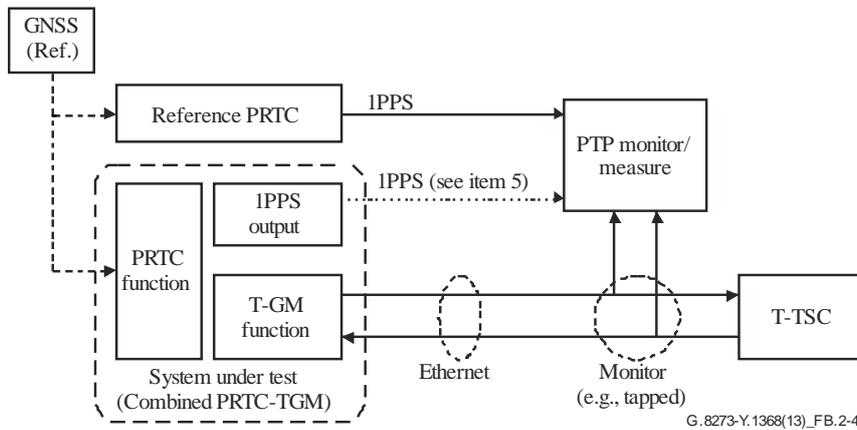


Figure B.2-4 – Passive measurement set-up for a combined "PRTC + T-GM"

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 system under test.
- 3) The system under test 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.

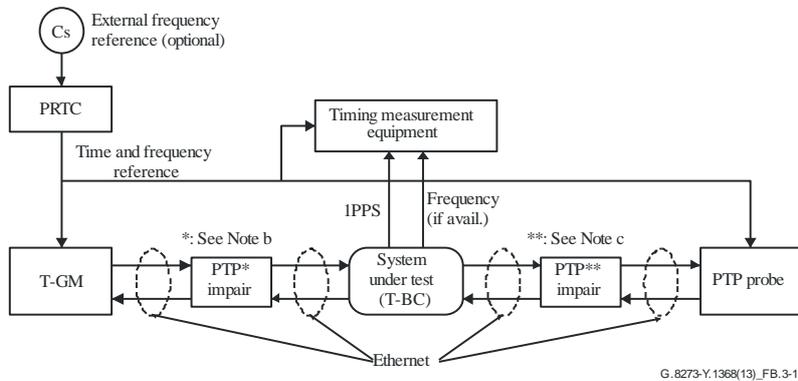


Figure B.3-1 – Active measurement set-up for systems with T-BC

With respect to the test arrangement shown:

- a) The 'Time Reference' 1PPS output is used as reference for time error measurement of the T-BC 1PPS output.
- b) 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.
- c) 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.
- d) 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.
- e) 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.

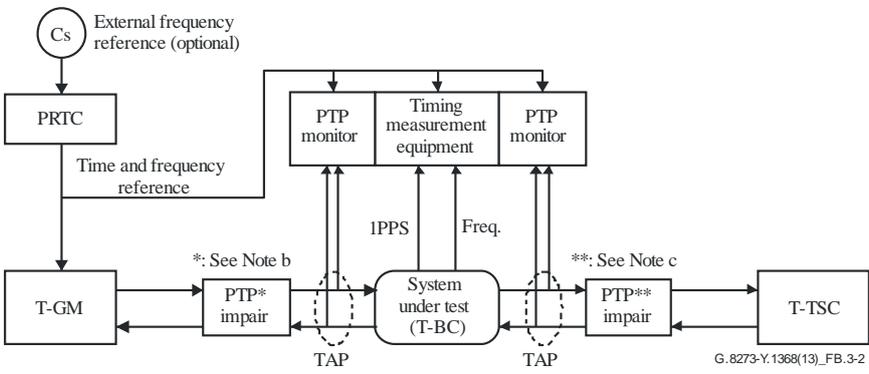


Figure B.3-2 – Passive measurement set-up for systems with T-BC

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

Measurement methods for transparent clocks are for further study.

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.

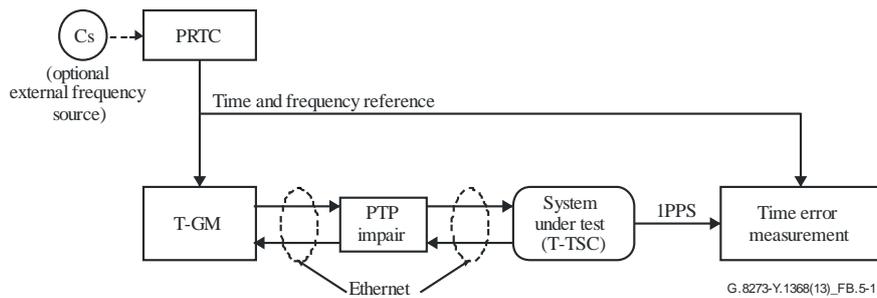


Figure B.5-1 – Measurement set-up for systems with T-TSC

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.

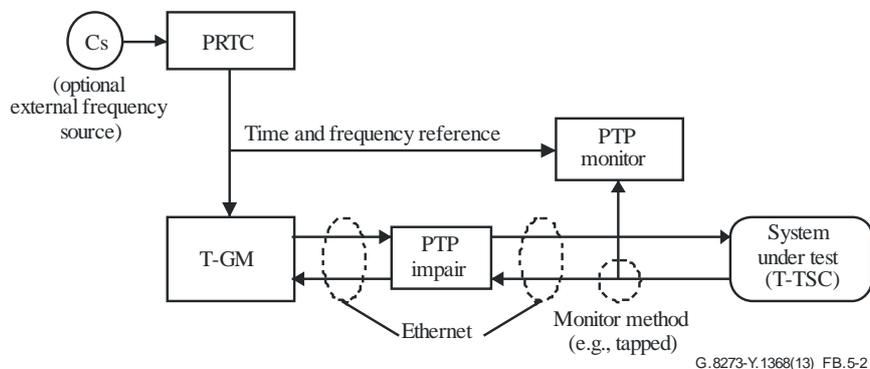


Figure B.5-2 – Measurement set-up for systems with T-TSC based on packet timing signal

ITU-T Y-SERIES RECOMMENDATIONS
**GLOBAL INFORMATION INFRASTRUCTURE, INTERNET PROTOCOL ASPECTS AND NEXT-
GENERATION NETWORKS**

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Numbering, addressing and naming	Y.500–Y.599
Operation, administration and maintenance	Y.600–Y.699
Security	Y.700–Y.799
Performances	Y.800–Y.899
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Service aspects: Interoperability of services and networks in NGN	Y.2250–Y.2299
Enhancements to NGN	Y.2300–Y.2399
Network management	Y.2400–Y.2499
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CLOUD COMPUTING	Y.3500–Y.3999

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

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