

Recommendation

ITU-T G.8273/Y.1368 (06/2023)

SERIES G: Transmission systems and media, digital systems and networks

Packet over Transport aspects – Synchronization, quality and availability targets

SERIES Y: Global information infrastructure, Internet protocol aspects, next-generation networks, Internet of Things and smart cities

Internet protocol aspects – Transport

Framework of phase and time clocks

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Transmission systems and media, digital systems and networks

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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 operates in the network architecture specified in Recommendations ITU-T G.8271, ITU-T G.8275 and the ITU-T G.8271.x-series of Recommendations.

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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 specified 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 specified in the ITU-T G.8273.x-series, and includes annexes specifying methods of their testing and measurement.

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 (2022), *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.8272] Recommendation ITU-T G.8272/Y.1367 (2018), *Timing characteristics of primary reference time clocks*.
- [ITU-T G.8272.1] Recommendation ITU-T G.8272.1/Y.1367.1 (2016), *Timing characteristics of enhanced primary reference time clocks*.
- [ITU-T G.8273.2] Recommendation ITU-T G.8273.2/Y.1368.2 (2023), *Timing characteristics of telecom boundary clocks and telecom time synchronous clocks for use with full timing support from the network*.
- [ITU-T G.8273.3] Recommendation ITU-T G.8273.3/Y.1368.3 (2020), *Timing characteristics of telecom transparent clocks for use with full timing support from the network*.
- [ITU-T G.8273.4] Recommendation ITU-T G.8273.4/Y.1368.4 (2020), *Timing characteristics of telecom boundary clocks and telecom time slave clocks for use with partial timing support from the network*.
- [ITU-T G.8275] Recommendation ITU-T G.8275/Y.1369 (2020), *Architecture and requirements for packet-based time and phase distribution*.
- [IEEE 1588] Either [IEEE 1588-2008] or [IEEE 1588-2019] depending on the specific implementation. See clause 5 for more details.
- [IEEE 1588-2008] IEEE Std 1588-2008, *IEEE Standard for a precision clock synchronization protocol for networked measurement and control systems*.
- [IEEE 1588-2019] IEEE Std 1588-2019, *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:

1 PPS	1 Pulse Per Second
cTE	constant Time Error
dTE	dynamic Time Error
DUT	Device Under Test
EEC	Ethernet Equipment Clock
eEEC	enhanced synchronous Ethernet Equipment Clock
ESMC	Ethernet Synchronization Message Channel
eSyncE	enhanced Synchronous Ethernet
GM	Grandmaster
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
LO	Local Oscillator
MTIE	Maximum Time Interval Error
PRC	Primary Reference Clock
PRTC	Primary Reference Time Clock
PTP	Precision Time Protocol
QL	Quality Level
SUT	System Under Test
SyncE	Synchronous Ethernet
T-BC	Telecom Boundary Clock
TDEV	Time Deviation
T-GM	Telecom Grandmaster
ToD	Time of Day
TR	Time Receiver
TT	Time Transmitter
T-TC	Telecom Transparent Clock
T-TSC	Telecom Time Synchronous Clock

5 Conventions

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

Within this Recommendation, some requirements are stated as requiring compliance to [IEEE 1588]. For implementations based on [IEEE 1588-2008], reference to [IEEE 1588] means compliance with

the 2008 edition. For implementations based on [IEEE 1588-2019], reference to [IEEE 1588] means compliance with the 2019 edition.

The terms dynamic time error (dTE) 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 specified or are to be so in the ITU-T G.8273.x-series of Recommendations.

The focus of this Recommendation is on packet-based methods for transferring time or phase. Specific methods based on the PTP [IEEE 1588] are considered.

The ITU-T G.8273.x-series of Recommendations specifies the items in the following list. However, it is important to note that as of the date of publication, ITU-T G.8273.1 has not yet been approved; its specifications are still under study and thus may be subject to change.

- Telecom grandmaster (T-GM) specification. The T-GM is a device consisting of a GM as defined in [IEEE 1588-2008] with additional performance characteristics. The details of T-GM are specified in [ITU-T G.8272]. Other types of T-GM are expected to be specified in ITU-T G.8273.1 (currently under study).
- Telecom boundary clock (T-BC) specification. The T-BC is a device consisting of a boundary clock as specified in [IEEE 1588-2008] 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 (T-TC) specification. The T-TC is a device consisting of a transparent clock as specified in [IEEE 1588-2008] with additional performance characteristics. [ITU-T G.8273.3] specifies T-TC.
- Telecom time synchronous clock (T-TSC) specification. The T-TSC is a device consisting of a timeReceiver clock as specified in [IEEE 1588-2008] with additional performance characteristics. [ITU-T G.8273.2] specifies T-TSC.
- Partial timing support T-BCs (T-BC-partial support), T-BC-assisted) and T-TSCs (T-TSC-partial support, T-TSC-assisted). The details of these clocks are specified in [ITU-T G.8273.4].

Annex A

Testing and measurement of time or phase clocks

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

A.1 Introduction

Measurement of time or phase behaviour of clocks is substantively different from measurement of their frequency behaviour. 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 can be applied to time or phase clocks and such measurements may have value when assessing their stability; such metrics are not sufficient to characterize their time error. One metric that is distinct from those of frequency is the constant time error (cTE). The use of constant, dynamic and frequency metrics to characterize stability of a time or phase clock is for further study.

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

A.1.1 TimeTransmitter port time-stamp error

There are four time stamps that are relevant in the PTP. These are as follows.

- Associated with the *SYNC* message:
 - 1) T_1 : time of departure from timeTransmitter port;
 - 2) T_2 : time of arrival at timeReceiver port.
- Associated with *DELAY_REQUEST* message:
 - 3) T_3 : time of departure from timeReceiver port;
 - 4) T_4 : time of arrival at timeTransmitter port.

Of these time stamps, T_2 and T_3 are struck at the timeReceiver 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 (SUT) 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 GM 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 timeTransmitter 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 timeTransmitter 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 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 timeTransmitter port can estimate the time of departure of a *SYNC* message from the timeTransmitter port by time-stamping the passage of the *SYNC* message. Denote this measurement by $T_{1\text{REF}}$. By parsing the *SYNC* message (or *FOLLOW_UP*), the time of departure of the *SYNC* message as struck by the timeTransmitter port, T_1 , is established. The accuracy of the time stamp is quantified by the time error (sequence) TE_1 given by:

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

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

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

The limit Y_1 is application dependent and is specified in the relevant clock specification. As recommended in [IEEE 1588], Y_1 is commensurate with the required accuracy of the application. The further allocation to cTE and dTE (time noise) and systematic errors is for further study.

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

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

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

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

The limit Y_4 is application dependent and is specified in the relevant clock specification. As recommended in [IEEE 1588], Y_4 is commensurate with the required accuracy of the application. The further allocation to cTE and dTE (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 timeTransmitter port. Similarly, TE_4 is measured by time-stamping the passage of a *DELAY_REQUEST* message at a calibrated distance from the timeTransmitter 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 timeTransmitter and the time of departure of a *DELAY_REQUEST* message to the timeTransmitter. This is depicted in Figure A.1-1.

Guidelines for the measurement include the following.

- a) The timeTransmitter device and the test device are provided with a common time or phase reference and it is assumed that any synchronization error associated with locking to this reference is negligible. Such synchronization errors should be maintained at a level to facilitate the verification of the time error limit. Any systematic errors associated with synchronization and 1 pulse/s (1 pulse per second; 1 PPS) 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 at 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 or phase reference is provided to the different pieces of equipment involved.

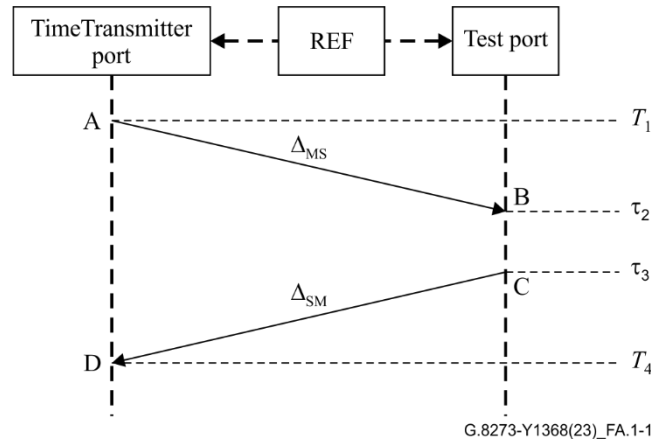


Figure A.1-1 – Depicting the situation where the system under test is connected to a test device and PTP messages are exchanged

At time A the timeTransmitter 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 timeTransmitter, 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 timeTransmitter 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 cTE and dTE (time noise) is for further study.

A.1.2 TimeTransmitter port time-transfer error

Considering a device downstream from the timeTransmitter 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 timeTransmitter 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 IEEE-1588-2008 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 cTE and the other is the dTE or time noise. The time noise generation requirement is for further study. The cTE component of the time error is derived by combining the cTE of each sequence computed separately.

For a timeTransmitter port, the cTE transfer requirement is satisfied if:

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

where the notation $\langle \rangle$ is used for the cTE estimation and X_{CONSTANT} is the prescribed limit for cTE generation for the timeTransmitter port provided in the appropriate Recommendation of the ITU-T G.8273.x series.

The implication of satisfying Equation A.1.10 is that the timeTransmitter port is capable of delivering time to a downstream device that is within X_{CONSTANT} of the underlying time clock of the timeTransmitter port, in terms of cTE.

A.2 Grandmaster clocks

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

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

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 [ITU-T G.8272 and [ITU-T G.8272.1].

See Figure A.2-1.

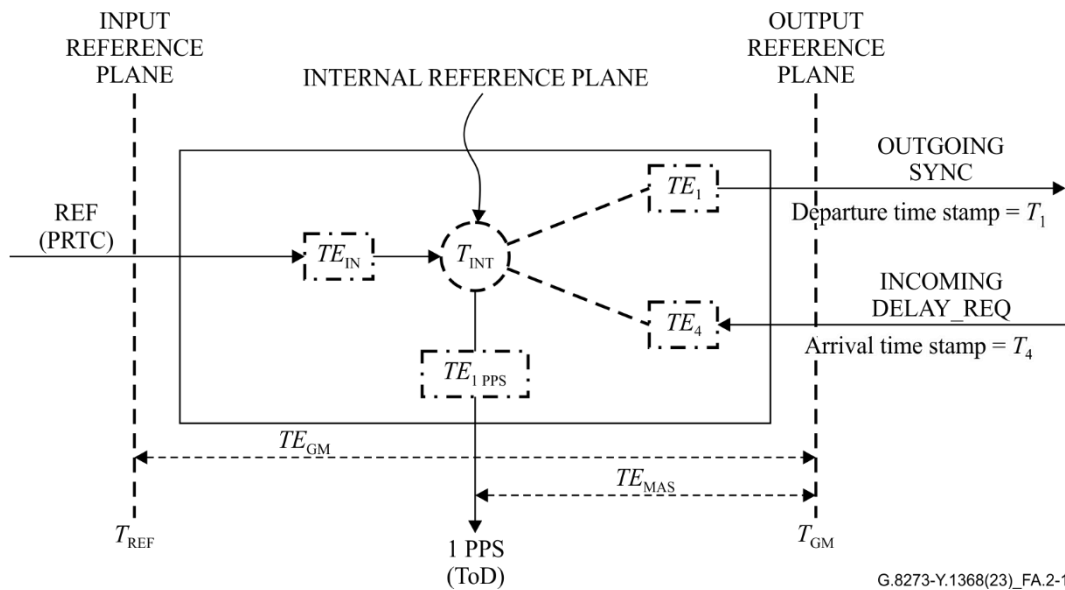


Figure A.2-1 – Noise generation model for a grandmaster clock

A GM 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 time of the T-GM, T_{GM} , is available via a 1 PPS (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_1 PPS 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 or a local oscillator (LO) is included in TE_{IN} . The timeTransmitter 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 timeTransmitter 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 LO or via the physical-layer reference (e.g., synchronous Ethernet (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 of X_{GM} are 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 timeTransmitter 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 (see 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:

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

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 1588 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) cTE;
- 2) time noise.

The time noise (dTE) 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 cTE component of the composite time error is computed as the cTE of each sequence separately following the procedure described in clause 3.1.20 of [ITU-T G.8260]. The cTE 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 cTE estimation and $X_{GM-CONSTANT}$ is the prescribed limit for cTE 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 cTEs in the forward and reverse directions, which in this case is the total cTE introduced.)

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

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 as follows.

- *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 timeTransmitter 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.

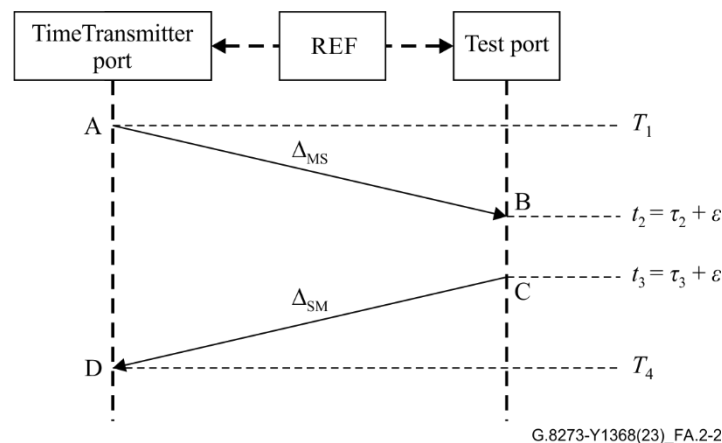


Figure A.2-2 – Depicting the situation where the SUT is connected to test device and PTP messages are exchanged

At time A, the timeTransmitter 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 timeTransmitter 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 τ_3 and the equivalent time at the timeTransmitter, t_3 , is given by:

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

The time of arrival at the timeTransmitter, 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:

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

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 to be operating correctly is, heuristically:

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

X_{GM} represents the actual requirement and 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 whose values 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:

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

where the REF 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 cTE and dTE (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 T-BC can be viewed as a clock that derives its timing reference from its timeReceiver port using PTP packet exchanges with an upstream timeTransmitter port. The same mathematical approach used previously for GMs 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 TIME_TRANSMITTER side of the T-BC. Denote this by T_{TT} . It is required that, as a minimum, the interconnecting medium (e.g., fibre) between the T-BC timeTransmitter port and the reference point D is calibrated to be symmetric.

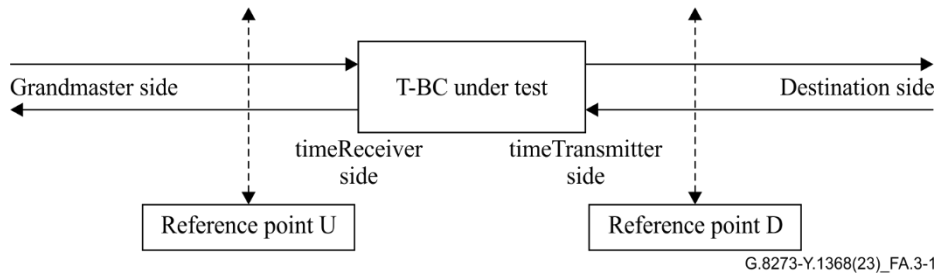


Figure A.3-1 – Demarcation of measurement points for testing BC performance

At reference point U (for "upstream"), a mechanism must be in place to measure the time at U as provided by the upstream clock. It is assumed that, as a minimum, the interconnecting medium (e.g.,

fibre) between the T-BC timeReceiver port and the reference point U is calibrated to be symmetric. Given this calibration, the time, T_{TR} , delivered by upstream timeTransmitter to the timeReceiver is established.

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

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

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 of 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. T_{TR} represents the time delivered by the upstream timeTransmitter to reference point U and T_{TT} represents the time delivered by the T-BC to reference point D.

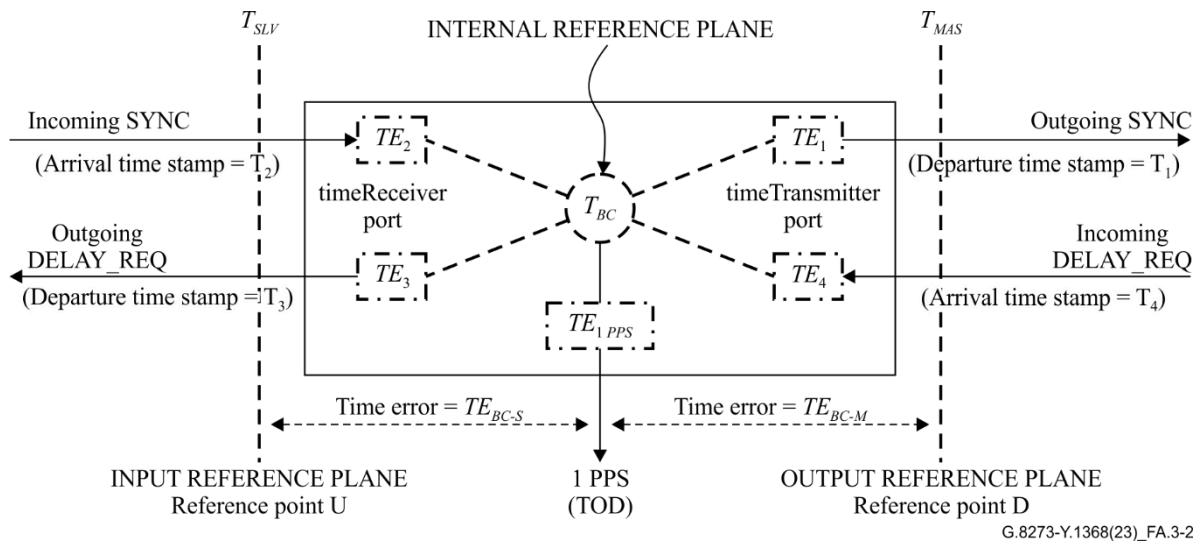


Figure A.3-2 – Time error generation components in a boundary clock

The boundary clock receives its reference from an upstream clock. The internal system time of the T-BC, T_{BC} , is generally available via a 1 PPS (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 $TE_{1 \text{ PPS}}$ term. The timeReceiver 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 although there could be noise generation associated with each of time stamps TE_2 and TE_3 , respectively. Denote the time error of the timeReceiver 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 timeReceiver port, a test system can provide an accurate time input or a monitoring device placed there can establish the correct value for T_{TR} and the effective time error generation in the timeReceiver clock portion of the T-BC can be measured by comparing T_{TR} and the 1 PPS output of the T-BC.

The timeTransmitter 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 or time-variable components in TE_1 and TE_4 can lead to cTE and dTE 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 timeReceiver port plus the timeTransmitter 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 LO or via the physical-layer reference (e.g., SyncE) and these are generally manifested in the timeReceiver 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_{TR}) or using a monitoring device to recover the time delivered at reference point U (T_{TR}), as well as recovering the time delivered by the T-BC at reference point D (T_{TT}).

Provided that a mechanism is provided to establish T_{TR} accurately, this provides the reference time for the test device that monitors the timeTransmitter side of the T-BC under test and the methodology established for testing GMs can be reapplied. That is, using T_{TR} 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). Denoting the (symmetric) cable delay by Δ , the time error components TE_1 and TE_4 are computed as:

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

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 1588 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 (dTE) generation requirement is for further study.

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

For a T-BC, the cTE generation requirement is satisfied if

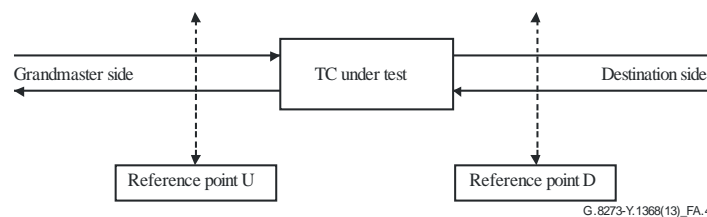
$$\frac{|\langle TE_1(n) \rangle + \langle TE_4(m) \rangle|}{2} < X_{BC-CONSTANT} \quad (A.3.4)$$

where the notation $\langle \rangle$ is used for the cTE estimation and $X_{BC-CONSTANT}$, the prescribed limit for cTE 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 clock that is within $X_{BC-CONSTANT}$ of the time delivered by the upstream clock to the T-BC, in terms of cTE.

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 the PTP [IEEE 1588]. This is achieved by adjusting the *correction_field* by an amount equal to the residence time. See Figure A.4.



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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 timeReceiver clock at point U will exhibit a time-offset from the timeTransmitter (on the GM side) of T_U . Likewise, a timeReceiver clock at point D will exhibit a time-offset from the same timeTransmitter 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 of X_{TC} are for further study.

NOTE – The details of TC are for further study.

A.5 Telecom time synchronous clocks

A simplified depiction of the time error generation in a T-TSC is shown in Figure A.5-1. T_{TR} represents the time delivered by the upstream clock to reference point U and T_{OUT} represents the time delivered by the T-TSC to the application.

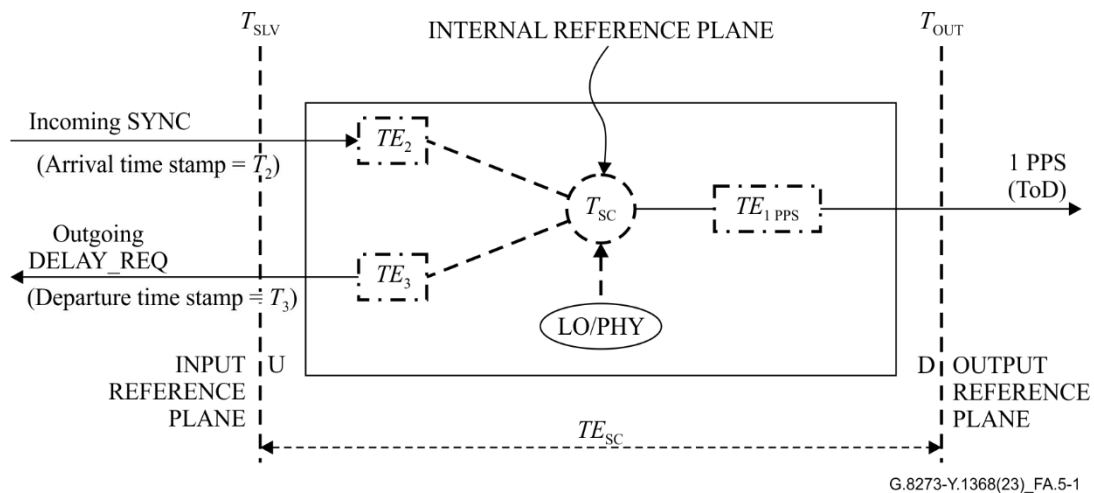


Figure A.5-1 – Time error generation components in a T-TSC

The T-TSC receives its reference from an upstream clock. The internal system time of the T-TSC, T_{SC} , is generally available to an external application via a 1 PPS (and ToD) interface or equivalent. There may be uncertainty in this output due to the $TE_{1 \text{ PPS}}$ 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 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, LO and unfiltered packet delay variation (dTE) present in the reference input. The LO function may include a physical layer assist (e.g., SyncE).

Figure A.5-1 considers only time errors. If the T-TSC also provides a frequency output, that output can be measured against the reference provided to the GM. The frequency output measurement can provide information of T-TSC wander at observation intervals less than 1 s and clock jitter, both unavailable via the 1 PPS. 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_{TR} . The effective time error generation in the clock, TE_{SC} , can be measured by comparing T_{TR} and the 1 PPS output of the T-TSC. The acceptable limits for time error generation of a T-TSC are application dependent and are given in [ITU-T G.8273.2] and [ITU-T G.8273.4].

The performance of the clock may be verified by observing T_3 at the input reference plane U that is a calibrated (time) distance from the timeReceiver port. This requires the clock to populate the T_3 time-stamp field with the precise time stamp for time of departure, with respect to the 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 interconnect 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.

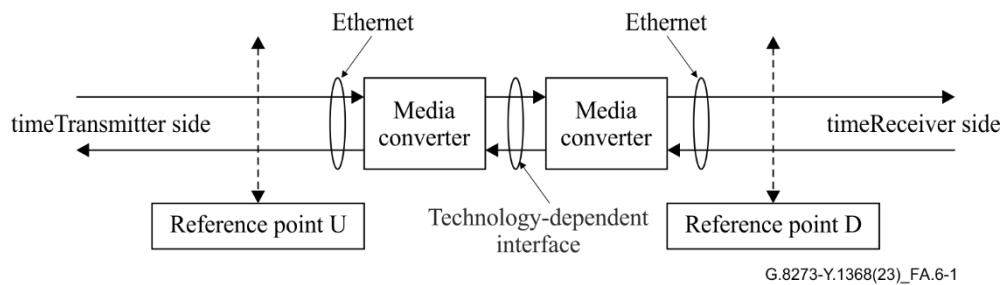


Figure A.6-1 – Demarcation of measurement points for testing media converter nodes

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 or 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 or 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 follow.

- a) A common time/phase reference (e.g., 1 PPS) must be used for all elements of the test system. An 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 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 syncE reference if the SUT utilizes the syncE physical layer clock.
- f) The equipment providing the PTP impair function supports syncE in those cases where the SUT utilizes the syncE (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 carrying traffic and PTP timing packets. If interfaces also carry traffic, external traffic must be present for all PTP tests (e.g., noise generation, noise transfer).
- i) It is expected that, for the type of measurements specified 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 $\geq 1\ 000$ s 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. The interfaces addressed in this annex are Ethernet; other interfaces are for further study.

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].

See Figure B.1-1.

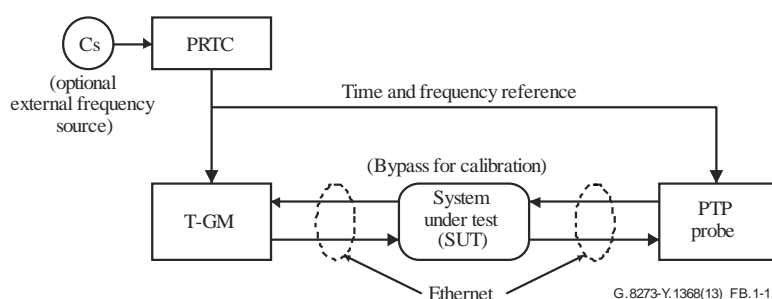


Figure B.1-1 – Active measurement set-up for systems with PTP time transfer

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.

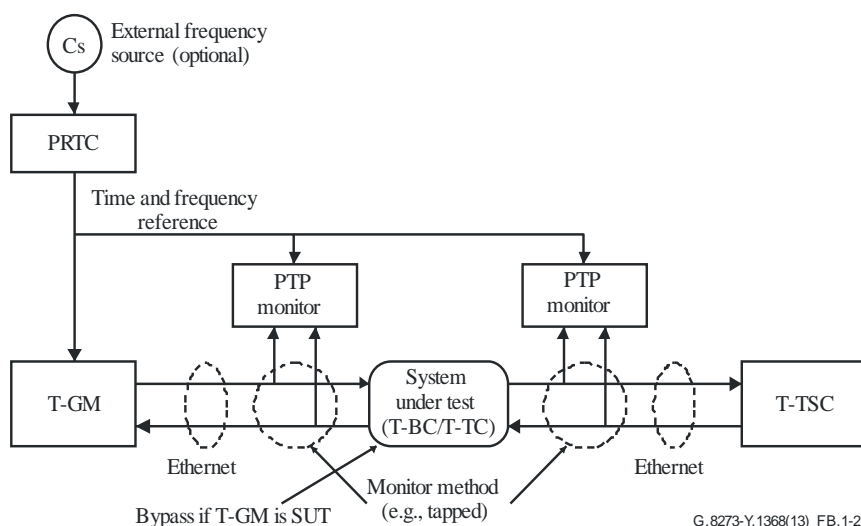


Figure B.1-2 – Passive measurement set-up for systems with PTP time transfer

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.

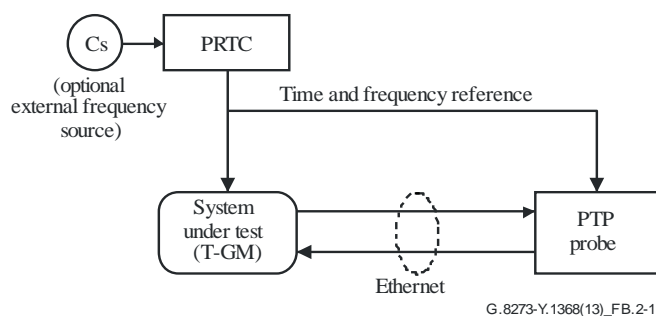


Figure B.2-1 – Active measurement set-up for (PTP) telecom grandmaster

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.

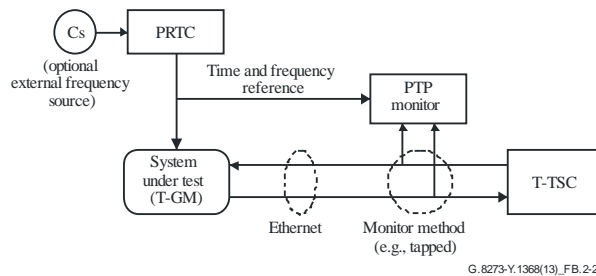


Figure B.2-2 – Passive measurement set-up for (PTP) telecom grandmaster

The T-TSC may be replaced by an aggregation of clocks either physically or logically in order to simulate the condition of multiple T-TSCs 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 in the same physical equipment.

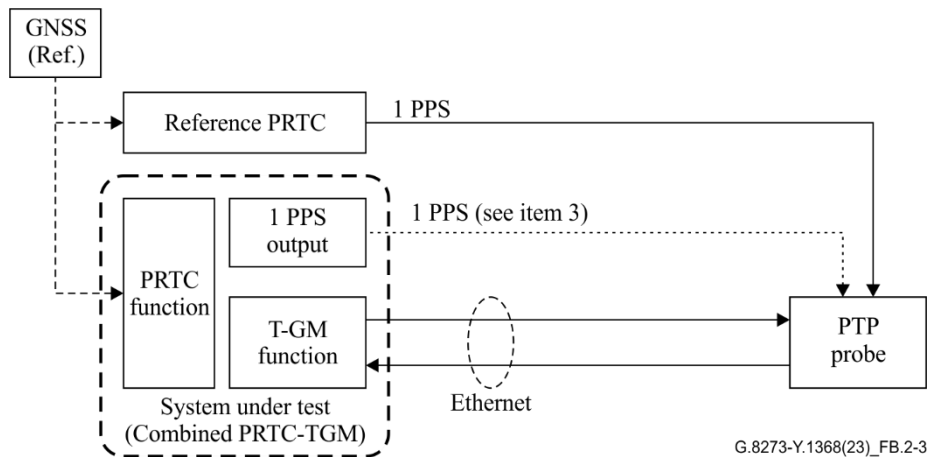


Figure B.2-3 – Active measurement set-up for a combined PRTC + T-GM

With respect to the arrangement shown, note the following.

- 1) As the SUT contains both the PRTC function and the T-GM function, the internal interfaces are vendor-specific. Providing a 1 PPS output permits equipment testing and verification.
- 2) The SUT PRTC, as well as the reference PRTC are provided with the same reference input. In 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 1 PPS 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 in the same physical equipment.

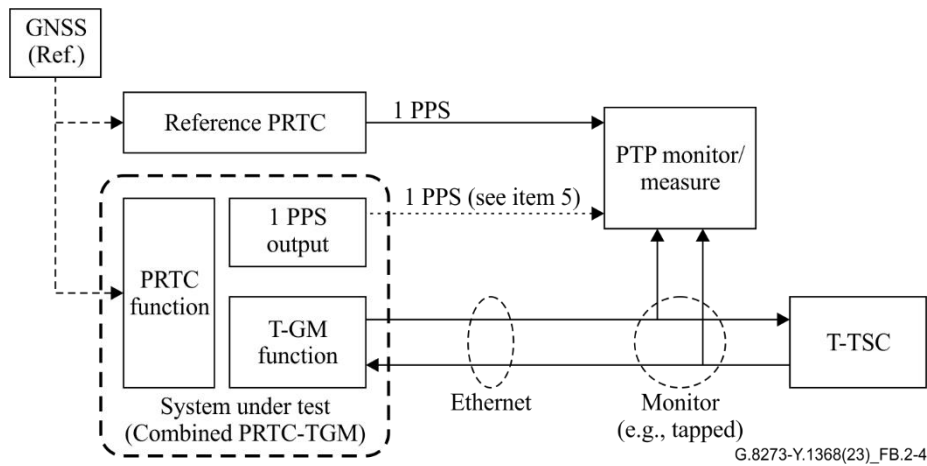


Figure B.2-4 – Passive measurement set-up for a combined "PRTC + T-GM"

With respect to the arrangement shown in Figure B.2-4, note the following.

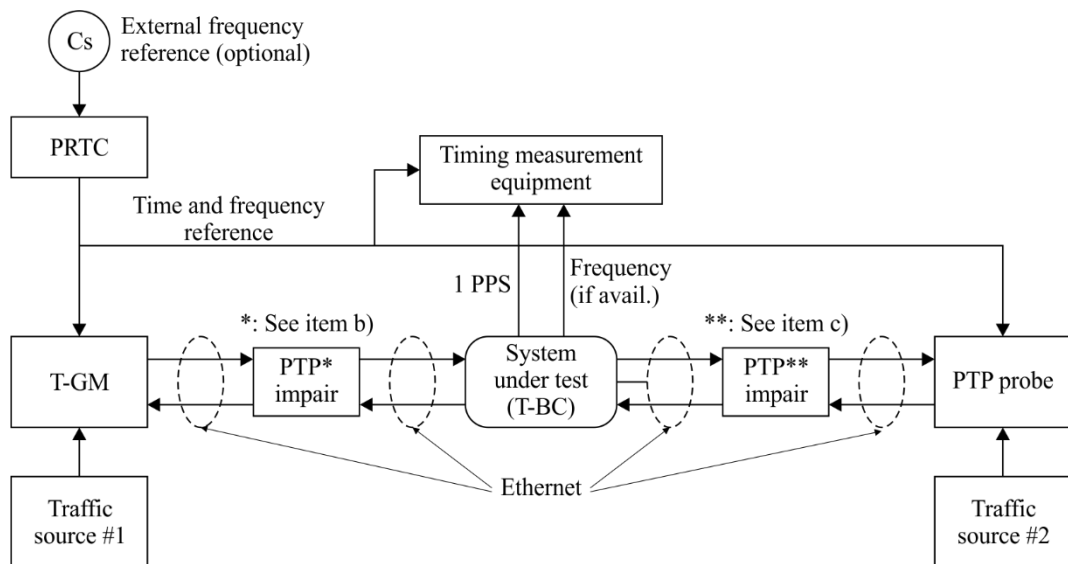
- 1) As the equipment under test contains both the PRTC function and the T-GM function, the internal interfaces are vendor-specific. Providing a 1 PPS output permits equipment testing and verification.
- 2) In the tapped monitor method, the T-TSC can be connected via a network; the monitor points remain at a calibrated distance from the timeTransmitter port of the SUT.
- 3) The SUT PRTC, as well as the reference PRTC are provided with the same reference input. In Figure B.2-4 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 clocks either physically or logically in order to simulate the condition of multiple T-TSCs 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 monitoring or measurement system cannot measure 1 PPS 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 1 PPS time error measurement is recommended to be performed at the same time.



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

With respect to the test arrangement shown in Figure B.3-1, note the following.

- a) The time reference 1 PPS output is used as reference for time error measurement of the T-BC 1 PPS 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 timeReceiver side of the T-BC.
- c) One PTP and physical layer frequency impair function is used to emulate network impairments between the SUT and the downstream clock in order to perform stress testing, where necessary, of the timeTransmitter 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 timeTransmitter and timeReceiver ports of the T-BC. This requires that the device(s) used for the T-GM and PTP Probe functions (or T-TSC in the passive measurement set-up) in these test environment support traffic generation (or traffic merging from an external source) to ensure the PTP ports are tested with traffic.
- e) If interfaces also carry traffic, interfering traffic must be present in both directions on each of the ports used for PTP messages on the SUT.
- f) 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.

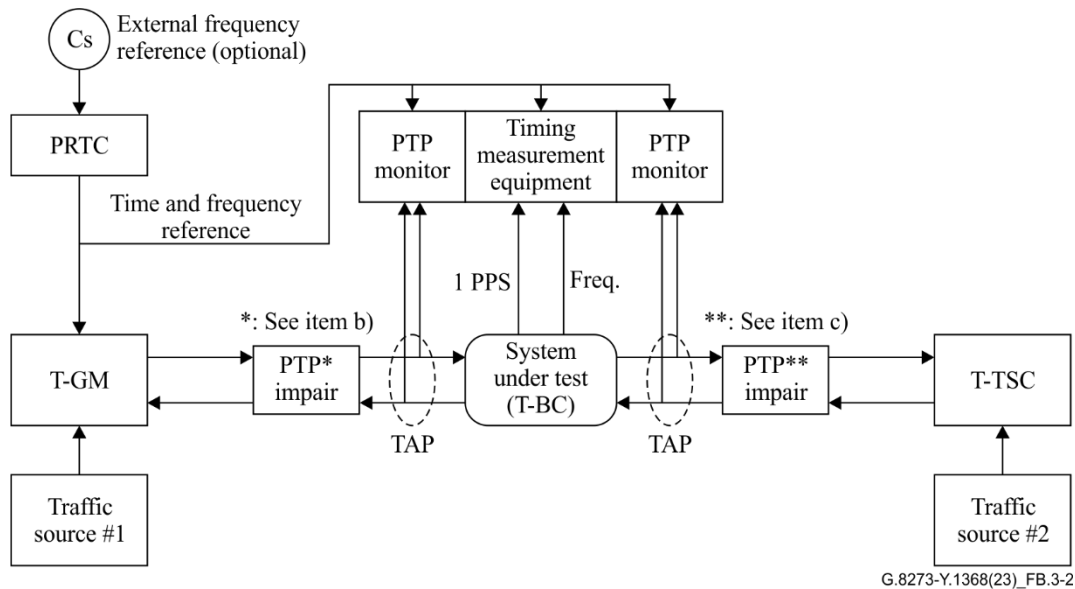


Figure B.3-2 – Passive measurement set-up for systems with T-BC

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.

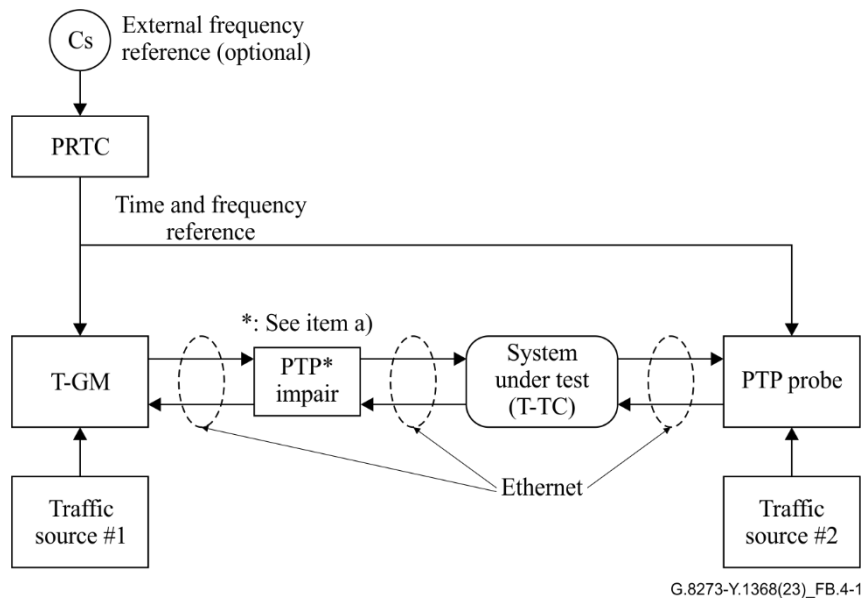


Figure B.4-1 – Active measurement set-up for systems with T-TC

With respect to the test arrangement shown in Figure B.4-1, note the following.

- a) 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.
- b) 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. This requires that the device(s) used for the T-GM and PTP Probe functions (or T-TSC in the

passive measurement set-up) in these test environment support traffic generation (or traffic merging from an external source) to ensure the PTP ports are tested with traffic.

- c) If interfaces also carry traffic, interfering traffic must be present in both directions on each of the ports used for PTP messages on the SUT.
- d) When calculating the T-TC noise generation and noise transfer using the set-up in Figure B.4-1, the PTP impairment must be known and compared with the PTP probe measurements.

NOTE – Appendix I describes an additional topology that can be used for evaluating performance of a T-TC but it does not replace that specified in this clause.

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.

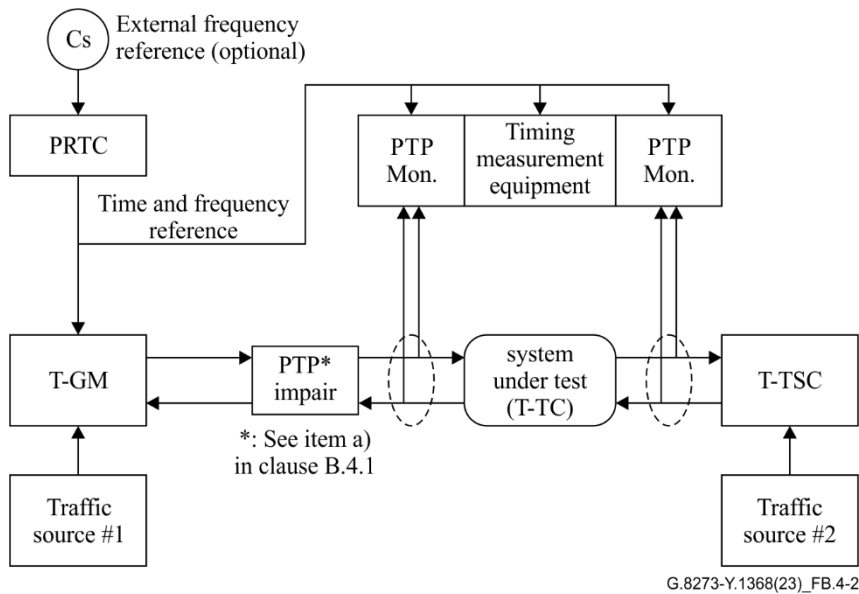


Figure B.4-2 – Measurement set-up for systems with T-TC

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 T-TSC

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

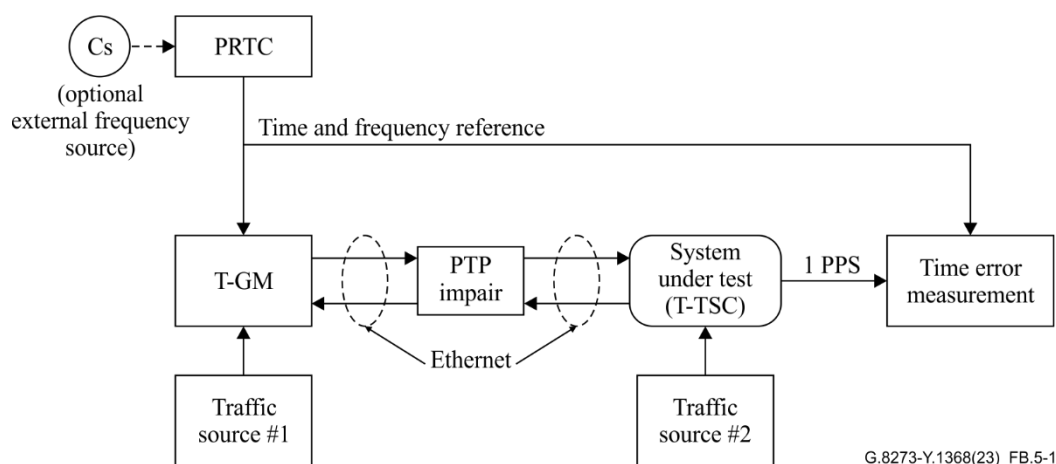


Figure B.5-1 – Measurement set-up for systems with T-TSC

With respect to the test arrangement shown in Figure B.5-1, note the following.

- The PTP impair function is used to emulate network impairments in order to perform stress testing where necessary.
- The equipment providing the PTP impair function supports syncE in those cases where the T-TSC utilizes the syncE (i.e., physical layer) as a frequency-assist mechanism and has the ability to introduce physical layer impairments (e.g., wander and frequency offset).
- If interfaces also carry traffic, suitable means are provided for injecting interfering traffic to mimic network loading conditions. The external traffic loading must be injected to the ports carrying the PTP messages. This requires that the device(s) used for the T-GM function and SUT (T-TSC) in these test environment support traffic generation (or traffic merging from an external source) to ensure the PTP ports are tested with external traffic.

[IEEE 1588] does not require a timeReceiver to send an accurate T_3 time stamp. However, if the timeReceiver provides an accurate T_3 time stamp, the performance of the clock may be evaluated by observing the embedded time stamp T_3 representing the time of departure of the *DELAY_REQUEST* message, with respect to the timeReceiver 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 1 PPS output signal, e.g., 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 timeReceiver port.

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

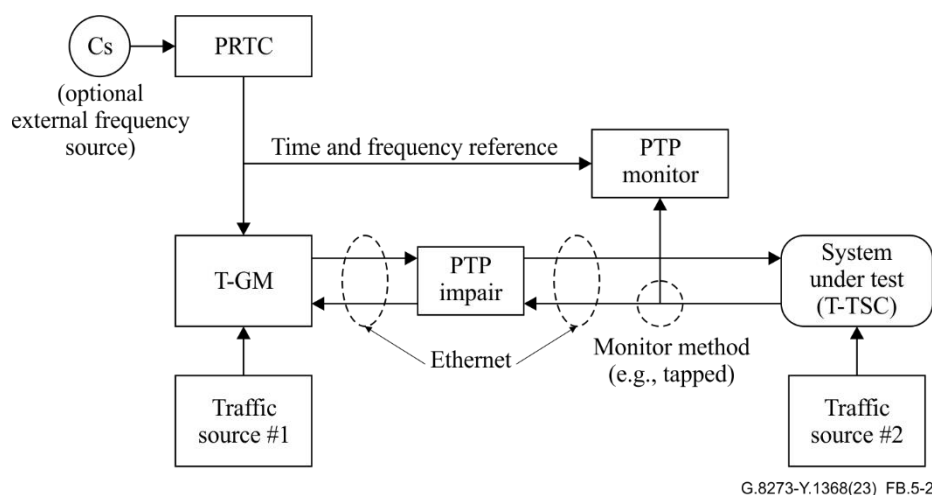


Figure B.5-2 – Measurement set-up for systems with T-TSC based on packet-timing signal

B.6 Traffic test pattern for time clocks

The interfering traffic used when testing T-BC, T-TC, and T-TSC includes sudden large and persistent changes in network load. It exercises the ability of the SUT to meet performance when there are different levels of traffic loading in both directions both at the physical interface and across the SUT. The distribution of packet sizes of the interfering traffic is:

- 5% of the load must be the largest size packets supported by the SUT (maximum transmission unit);
- 55% of the load must be large size packets (1 518 octets);
- 30% of the load must be small size packets (64 octets);
- 10% of the load must be medium size packets (576 octets).

Largest size packets will occur in bursts lasting between 0.1 s and 3.0 s.

Large size packets will occur in bursts lasting between 0.1 s and 3.0 s.

NOTE 1 – Due to constraints of the test equipment, it may not be possible to test the largest size packet supported by the device under test (DUT). In this case, the largest packet size supported by both the test equipment and the DUT should be used.

The loading of the interfering traffic is as follows.

- In the forward direction: Start with network disturbance load at 80% for time T , drop to 20% for time T , increase back to 80% for time T , drop back to 20% for time T , increase back to 80% for time T , drop back to 20% for time T . Simultaneously, in the reverse direction: Start with network disturbance load at 50% for approximately time $1.5 * T$, drop to 10% for time T , increase back to 50% for time T , drop back to 10% for time T , increase back to 50% for time T , drop back to 10% for approximately time $0.5 * T$ (see Figure B.6-1).

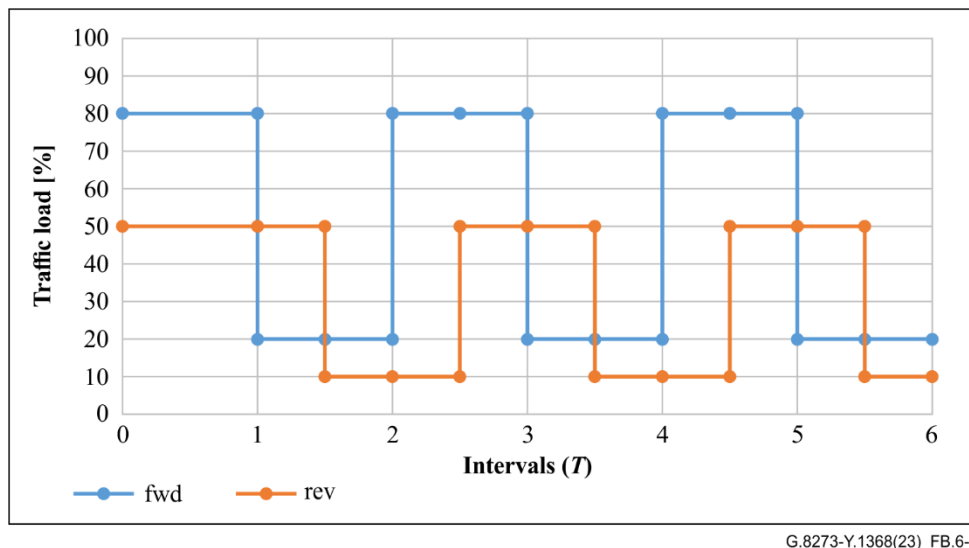


Figure B.6-1 – Traffic load for testing time clocks

The duration of each traffic load level (T) may depend on the clock under test. The expectations are that T for an ITU-T G.8273.2 or ITU-T G.8273.3 clock can be relatively short but a minimum of 5 min and for an ITU-T G.8273.4 clock can be relatively long, but a minimum of 1 h.

NOTE 2 – There are additional, optional tests for T-TC specified in Appendix I of [ITU-T G.8273.3].

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.

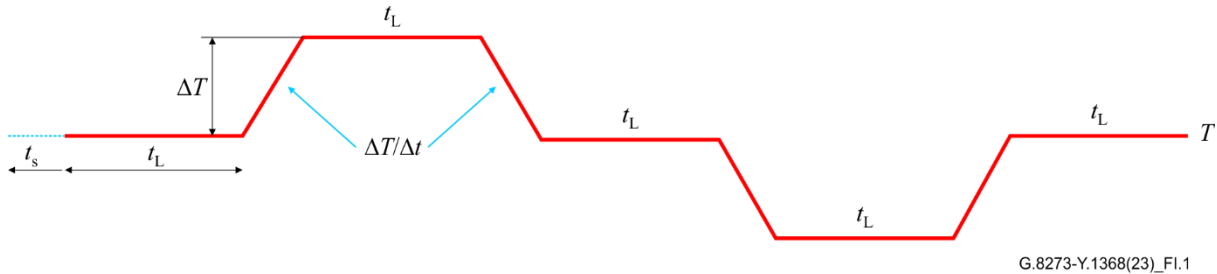


Figure I.1 – Temperature profile

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_{nom} and $T_{\max} - \Delta T$.

The test stabilization 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 ΔT and the ramp rate $\Delta T/\Delta t$ should be aligned to the environmental profile.

As an example, the constrained temperature excursion ΔT could be set to 20 °C and the ramp rate $\Delta T/\Delta t$ to 0.5 °C/min, 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 a 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.

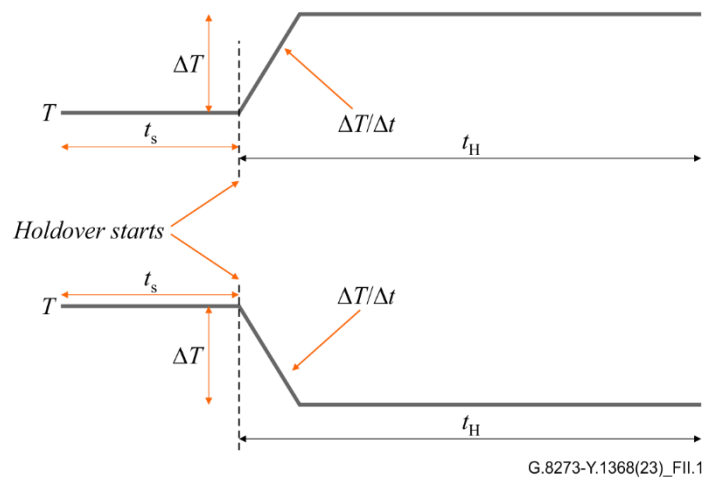


Figure II.1 – Variable temperature profile for holdover testing

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_{nom} and $T_{\max} - \Delta T$.

The test stabilization time, t_s , 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 ΔT and the ramp rate $\Delta T/\Delta t$ should be aligned to the environmental profile.

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

Appendix III

Physical layer frequency clock transient testing methodology

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

This appendix addresses the test methodology to measure the effects of a physical layer frequency input (e.g., SyncE/enhanced synchronous Ethernet (eSyncE)) 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 cases 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.

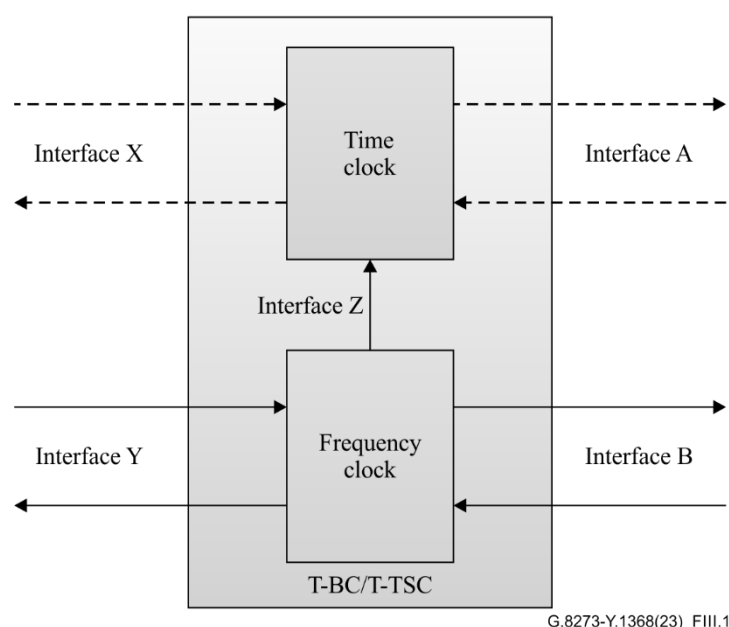


Figure III.1 – Example NE with SEC/eSEC and T-BC functions

For all test cases, 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].

Test case 1

This test case applies a phase transient to the physical layer frequency (e.g., SyncE/eSyncE) input coincident with a change in Ethernet synchronization message channel (ESMC) indicating a re-arrangement operation at the previous synchronous equipment clock (e.g., an Ethernet equipment clock (EEC)) or the enhanced synchronous equipment clock (e.g., an enhanced synchronous Ethernet equipment clock (eEEEC)) in the chain. It verifies that a T-BC under test properly limits the phase and time error at the PTP output during a re-arrangement of the physical layer frequency reference (e.g., SyncE/eSyncE), as required in Annex B or C of [ITU-T G.8273.2].

- 1) Input an ideal physical layer frequency clock (e.g., SyncE/eSyncE) 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 physical layer frequency (e.g.; SyncE/eSyncE) transient input signal pattern applicable to the DUT:
 - the applicable test pattern for an upstream synchronous equipment clock (i.e., ITU-T G.8262 transient noise) is shown in Figure III.2;

- the applicable test pattern for an upstream enhanced synchronous equipment clock (i.e., ITU-T G.8262.1 transient noise) is shown in Figure III.3.

In both cases, the pattern is applied at interface Y, and ESMC is sent 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 s (the longest duration before the second transient) after the start of the physical layer frequency clock (e.g., SyncE/eSyncE) input transient.
- 5) Send ESMC with QL restored to QL-PRC at interface Y after the 15 s 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 s and end the test.

The transient input signal pattern applicable to a synchronous equipment clock (e.g., SyncE), specified in [ITU-T G.8262], is shown in Figure III.2.

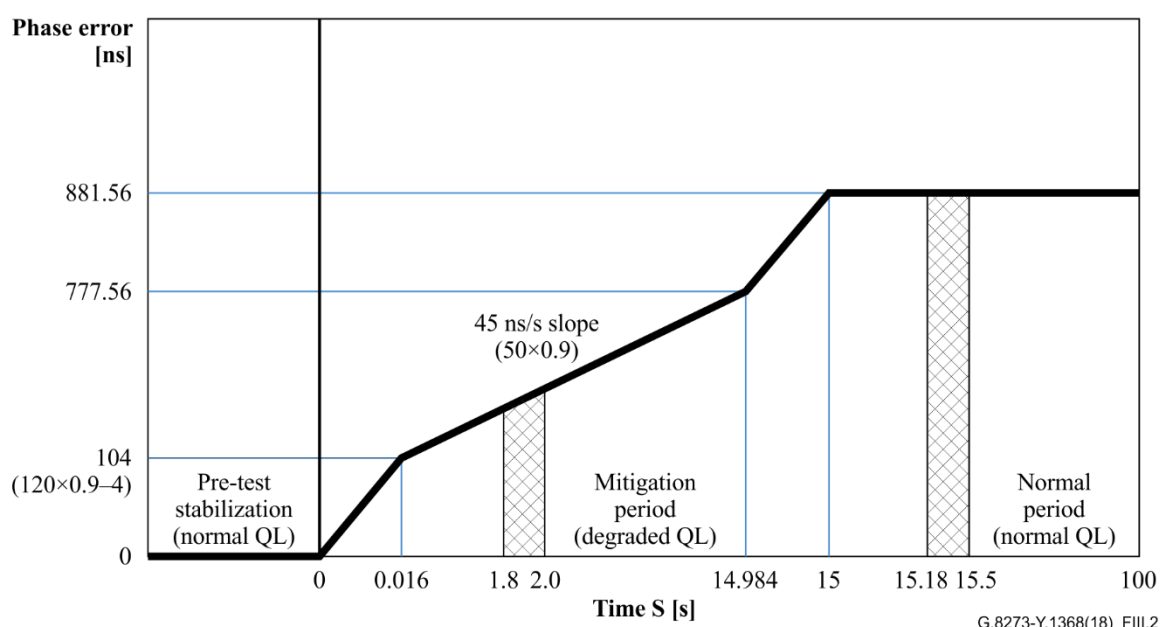


Figure III.2 – Test case 1 synchronous equipment clock (e.g., SyncE) transient input pattern

The transient input signal pattern applicable to an enhanced synchronous equipment clock (e.g., SyncE), specified in [ITU-T G.8262.1], is shown in Figure III.3.

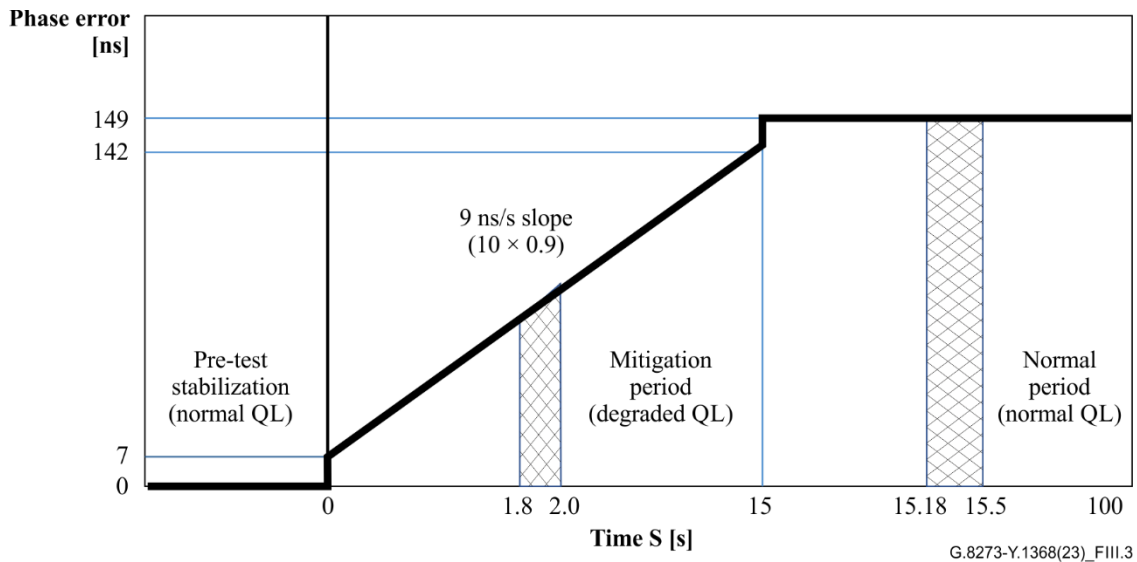


Figure III.3 – Test case 1 enhanced synchronous equipment clock (e.g., eSyncE) transient input pattern

Test case 2

This test case disconnects the physical layer frequency (e.g., SyncE/eSyncE) input, creating a re-arrangement operation in the synchronous equipment clock (e.g., an EEC) or the enhanced synchronous equipment clock (e.g., an eEEC) included in the T-BC under test. It verifies that a T-BC under test properly limits the phase and time error at the PTP output during a re-arrangement of the physical layer frequency (e.g., SyncE/eSyncE), as required in Annex B or C of [ITU-T G.8273.2].

- 1) Input an ideal physical layer frequency (e.g., SyncE/eSyncE) 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 of the physical layer frequency clock (e.g., SyncE/eSyncE) link at interface Y.

NOTE 1 – Disconnecting the physical layer frequency clock (e.g., SyncE/eSyncE) link can be accomplished by several methods (e.g., disconnecting the cable, disabling the port).

- 4) After 15 s, restore the physical layer frequency clock (e.g., SyncE/eSyncE) input link at interface Y.
- 5) Wait 85 s and end the test.

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

Test case 3

This test case degrades the QL value in the ESMC messages applied to the physical layer frequency clock (e.g., SyncE/eSyncE) input of the T-BC under test without applying a phase transient. It does not verify that the T-BC under test properly limits the phase and time error at the PTP output during a re-arrangement of the physical layer (e.g., SyncE/eSyncE) frequency transport, since there is no phase transient applied to the input. Therefore, it is not a confirmation that the requirements of Annex B or C of [ITU-T G.8273.2] are met, but it might help to verify whether any action itself taken by the T-BC due to the change of the QL has caused a performance degradation.

- 1) Input an ideal physical layer frequency clock (e.g., SyncE/eSyncE) 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 s, restore the input ESMC with QL restored to QL-PRC at interface Y.
- 5) Wait 85 s 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 1 PPS can be considered as 1 packet/s.

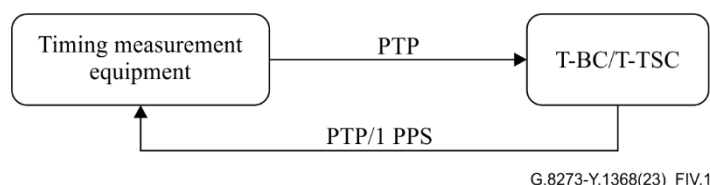


Figure IV.1 – T-BC/T-TSC noise transfer test installation

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 Equation (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 Equation (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 Equation (IV.6) and Equation (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, Equations (IV.6)-(IV.8) can be represented by the physical module in Figure IV.2.

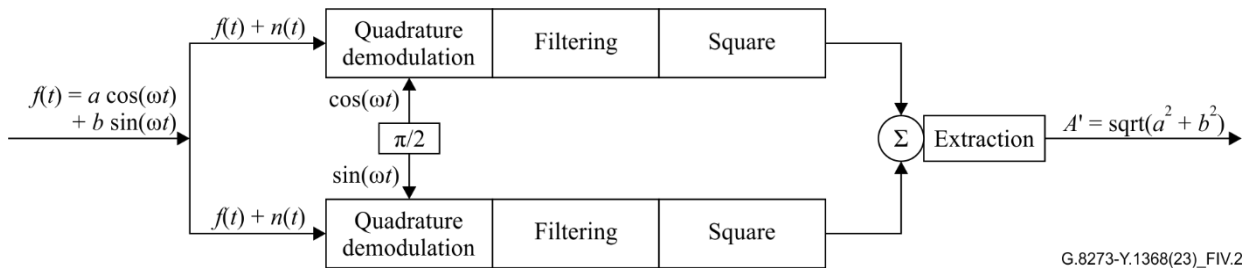


Figure IV.2 – Quadrature balanced demodulation system

The left-hand sides of Equations (IV.6) and (IV.7) are similar to quadrature demodulation as shown in Figure IV.2, in which the summation can be considered as the filtering operation, and Equation (IV.8) equals 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 the 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 is the amplitude A' after taking the square root.

If the DUT is ideal, its noise $n(t) = 0$, and the output amplitude series $\{A'_i\}$ has the constant value A . If the DUT is not ideal, its noise is $n(t) \neq 0$; then, as the number of samples 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 the least squares 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 (IV.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*.
- [b-ITU-T G.8271.1] Recommendation ITU-T G.8271.1/Y.1366.1 (2022), *Network limits for time synchronization in packet networks with full timing support from the network*.

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