International Telecommunication Union

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TELECOMMUNICATION
STANDARDIZATION SECTOR
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G.8263/Y.1363

Amendment 2

(05/2014)

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 AND NEXT-GENERATION NETWORKS

Internet protocol aspects – Transport

Timing characteristics of packet-based equipment clocks

Amendment 2

Recommendation ITU-T G.8263/Y.1363 (2012) – Amendment 2

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ITU-T G-SERIES RECOMMENDATIONS

TRANSMISSION SYSTEMS AND MEDIA, DIGITAL SYSTEMS AND NETWORKS

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

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

Recommendation ITU-T G.8263/Y.1363

Timing characteristics of packet-based equipment clocks

Amendment 2

Summary

Amendment 2 to Recommendation ITU-T G.8263/Y.1363 (2012) adds text to Appendix I, "Packet delay variation noise tolerance – testing methodology", which was previously marked as 'for further study'. It also replaces a sentence in clause 7.1 and adds a note in clause 7.1.

History

Edition	Recommendation	Approval	Study Group	Unique ID*
1.0	ITU-T G.8263/Y.1363	2012-02-13	15	11.1002/1000/11524
1.1	ITU-T G.8263/Y.1363 (2012) Amd. 1	2013-08-29	15	11.1002/1000/12014
1.2	ITU-T G.8263/Y.1363 (2012) Amd. 2	2014-05-14	15	11.1002/1000/12191

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

FOREWORD

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

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

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

NOTE

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

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

Recommendation ITU-T G.8263/Y.1363

Timing characteristics of packet-based equipment clocks

Amendment 2

1) Clause 7.1, PEC-S-F

Replace the following text:

The PEC-S-F must tolerate the noise at the limits specified in clause 8 of [ITU-T G.8261.1] (PDV network limits at point C).

with:

The PEC-S-F must tolerate the noise at the limits specified in clause 8.1.1 of [ITU-T G.8261.1] (PDV network limits at point C).

Add the following new note, Note 4, after Note 3.

NOTE 4 – As described in [ITU-T G.8261.1], clause 8.1.2, many networks may exhibit lower packet delay variation compared with the network limit for HRM-1 specified in [ITU-T G.8261.1], clause 8.1.1. This Recommendation defines one type of packet slave clock that is suitable for use with HRM-1, as described in [ITU-T G.8261.1], clause 8.1.1. Some operators may decide to use a different type of packet slave clock in case their network limits fit with clause 8.1.2 of [ITU-T G.8261.1]; this alternate type of packet slave clock is for further study.

2) Appendix I

Replace the whole of Appendix I with the text below.

Appendix I

Packet delay variation noise tolerance – testing methodology

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

While suitable test signals that check conformance to the masks in [ITU-T G.8261.1] (Case 3 of [ITU-T G.8261.1], as defined in reference point D in Figure 3 of [ITU-T G.8261.1]) are being studied, the testing methodologies described in clause I.2 below can be used to generate suitable packet delay variation test patterns. As such, the applicable mask is that which is shown in [ITU-T G.8261.1], Table 1 and Figure 4; no other masks are appropriate.

These methodologies are applicable only to the HRM-1 of [ITU-T G.8261.1]. Suitable methodologies for the HRM-2 are for further study. Other methodologies for generating suitable test signals that check conformance to the masks in [ITU-T G.8261.1] for the HRM-1 are also possible; this is for further study.

I.1 Testing set-up for PDV noise tolerance testing

The general testing set-up for PDV noise tolerance testing is shown in Figure I.1.

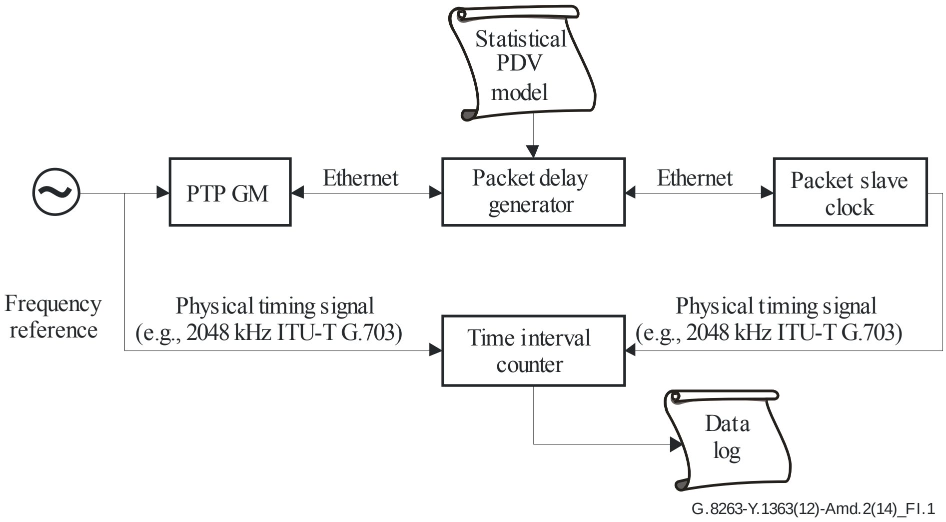


Figure I.1 – PDV noise tolerance testing set-up

The whole experiment is timed by a frequency reference clock, e.g., a caesium primary reference clock (PRC). This generates the input reference for a PTP grandmaster. The Sync messages generated by the PTP GM are delayed by a packet delay generator, and correspondingly the Delay_Request messages generated by the packet slave clock are also delayed using the same packet delay generator.

The delay sequences are generated by means of a statistical model, with the parameters chosen to generate a delay distribution with properties similar to the network limits criterion defined in [ITU-T G.8261.1] (i.e., for the HRM-1: 1% of the packets experiencing a delay within 150 µs of the minimum delay in each observation interval of 200 s). Several methodologies for generating suitable PDV patterns are possible, some of which are described for information purposes in clause I.2 below.

In general, it is recommended that the two delay sequences for the Sync and Delay_Request messages are similar in properties, being generated using the same statistical model, but not identical. This avoids correlation effects where the sequences use similar values at the same time.

The packet slave clock generates a physical output timing signal (e.g., a 2048 kHz ITU-T G.703 signal) which is compared back to the timing signal from the frequency reference by a time interval counter. The data log can then be compared to the output mask defined in Figure 4 of [ITU-T G.8261.1] to check the compliance of the slave.

The test procedure is to be carried out under constant temperature conditions (within ±1 K): Any stress testing under a noisy thermal environment is for further study.

When measuring PDV tolerance, the PDV test pattern should start to be applied before communication between the packet master clock and the packet slave clock is established. This order of operations will ensure that all "Event" packets are impacted by the PDV test pattern.

NOTE 1 – A stabilization period is required when applying the PDV test patterns to the packet slave clock, before verifying the output signal produced by the packet slave clock is within acceptable limits. The duration of this stabilization period is for further study.

NOTE 2 – In general, it is the intention of PDV tolerance testing that the packet slave clock does not have prior knowledge of packet master clocks from previous measurements. In a practical test set-up, steps may be taken to ensure that the packet slave clock does not have this prior knowledge. For example, the packet slave clock may need to be restarted or even power cycled between measurements. However, it should be noted that in the case of power cycling the required stabilization period will likely increase.

NOTE 3 – The recommended warm-up time of the equipment should be followed when performing the PDV tests.

I.2 Test methodologies

Three methods for generating suitable PDV test patterns that check conformance to the masks specifying the PDV network limits in [ITU-T G.8261.1] for the HRM-1 are described in this clause:

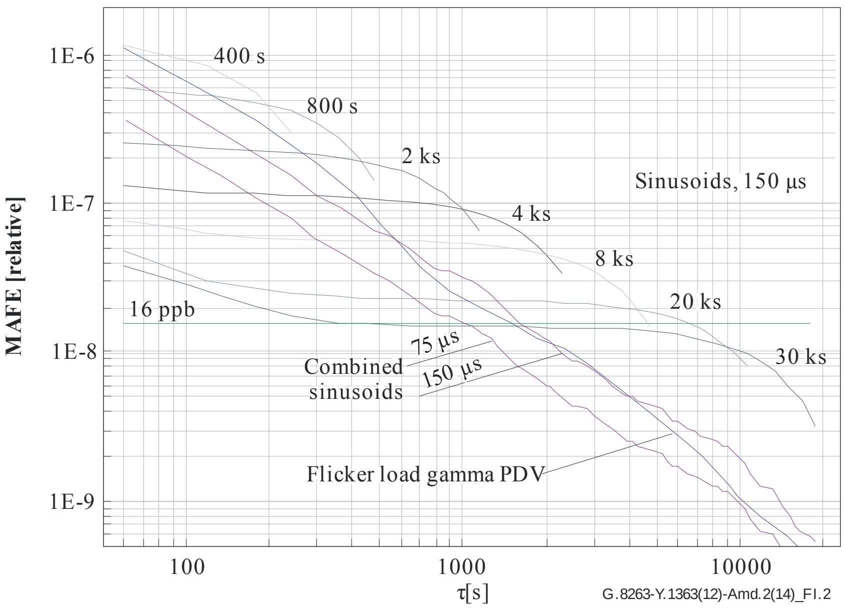
- PDV patterns based on flicker noise
- PDV patterns based on combined sinusoidal waveforms
- PDV patterns based on a single sinusoidal waveform.

Indications about the rationale for using each method are given in each subclause. Table I.1 below summarizes the pros and cons of each method.

Table I.1 – Comparison of the methods for PDV noise tolerance testing

Method	Pros	Cons
Flicker noise	Simple test, with limited duration Emulates some typical characteristics of packet networks	Does not take into account complex/extreme network scenarios, e.g., with floor delay movements
Combined sinusoidal waveforms	Simple test, with limited duration Emulates some typical characteristics of packet networks Includes floor delay movements, emulating moderate variations of traffic load	Does not take into account extreme network scenarios, e.g., low-noise delay floor moving full swing, defined by the network limit in a worst-case time frame.
Single sinusoidal waveform (optional)	Stress test corresponding to worst case scenarios, with extreme variations of the load (e.g., up to 100% of output ports capacity in all the nodes of the network), with important floor delay movements May allow in some cases determining the bandwidth of the slave clock	Long test duration when low frequencies are used Does not emulate typical characteristics of real networks

Figure I.2 summarizes the MAFE curves of the delay test patterns using 1% minimum selection and 60 s selection window. The PDV patterns represented by curves at higher tau values require higher stability of the clock in order to remain within the clock output limit.



NOTE – The applicable network limit values are stated in microseconds.

Figure I.2 – MAFE curves of the test patterns

NOTE – The generation of PDV patterns that implement the maximum tolerance allowed are artificially generated with these methods. As such, they may not represent PDV that may exist or occur in a real deployment or PDV that would be generated as a result of a packet timing master sending packets across a packet network. Some of the methodologies described to generate PDV patterns, especially the third one (single sinusoidal waveform), may prevent the full benefits of advanced filtering techniques. As a result, in order to successfully tolerate these artificial PDV patterns a narrower clock bandwidth and a local oscillator which is very stable may be required.

I.2.1 PDV patterns based on flicker noise

The method for generating PDV patterns described in this clause consists of a combination of flicker noise with a probability density function given by a gamma distribution as a statistical model of PDV.

Purpose and applicability

This method is based on a simplified statistical model for a network experiencing bursty traffic. Previous studies of Internet traffic ([x], [y]) have shown that the traffic distribution is bursty at many different scales, and that this self-similar behaviour can be represented by using flicker noise to modulate the traffic load. Secondly, it can be shown that the queueing action of a packet switch or router imposes a gamma distribution on the probability density function of the delays through the switch or router.

The resulting statistical model can be shown diagrammatically in Figure I.3:

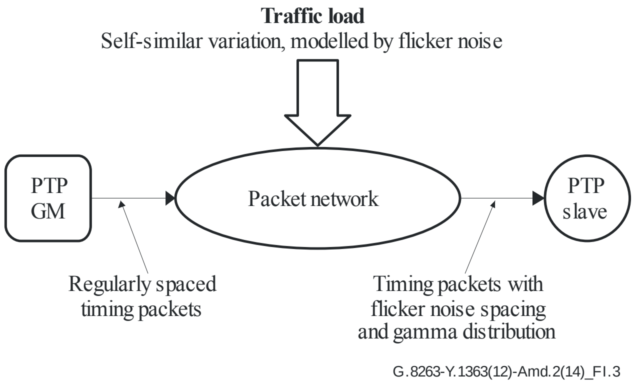


Figure I.3 – Statistical model of PDV for timing packets

It does not include the potential transients which can occur in packet networks, such as floor delay steps or floor delay variations. In addition, it may not model accurately a network which has significant non-bursty traffic (e.g., CBR traffic).

This method is therefore considered suitable as a minimum test for characterizing the noise tolerance of a packet slave clock. Additional testing is recommended to ensure that the packet slave clock will tolerate more complex network situations with transients.

Parameters and example

The parameters of the PDV pattern, including the standard deviation of the flicker pattern and the alpha and beta parameters of the gamma function, are related to physical characteristics of the network, such as the total load on the network, the individual load on the output port of each switch, and the number of switches in the network.

The procedure for defining a PDV sequence is as follows:

1) Produce a flicker sequence representing values of load between 0% and 100%.
2) Map the individual values of load in the flicker sequence to gamma PDV distributions specified by α, β and ρ.

Generation of the flicker sequence of load values

The flicker sequence of load values is generated by using the technique of Barnes, Jarvis and Greenhall. The technique is described in [b-Barnes & Greenhall], with additional details and generalizations given in [b-Barnes & Jarvis] and [b-Corsini & Saletti]. In this technique, a sequence of independent and identically distributed random samples is input to a bank of cascaded lead/lag filters whose frequency response approximates a transfer function that is inversely proportional to the square root of *f*, i.e.:

$$H(f) = \frac{1}{\sqrt{f}} \tag{I-1}$$

where *f* is the Fourier frequency and *H*(*f*) is the frequency response. If white noise, with constant power spectral density (PSD) *A*, is input to this filter, the power spectral density of the output is:

$$S_{out}(f) = |H(f)|^2 A = \frac{A}{f} \tag{I-2}$$

The PSD given by Equation (I-2) represents flicker noise, i.e., it is proportional to 1/*f*.

The bank of lead/lag filters is sometimes referred to as a Barnes/Jarvis/Greenhall filter, and each lead/lag filter in the bank is sometimes referred to as a stage of the Barnes/Jarvis/Greenhall filter. Each stage has approximately constant gain at low frequency and high frequency, with the low-frequency gain greater than the high-frequency gain and a −20 dB/decade transition between the low and high-frequency regions. This results in a frequency response for the Barnes/Jarvis/Greenhall filter that resembles a series of "steps", i.e., flat levels connected by −20 dB/decade slopes. The spacing of the poles and zeros of the stages are chosen so that the gain is inversely proportional to the square root of frequency. The number of stages and spacing of the poles and zeros determines the range of frequency over which the filter operates, i.e., the implementation of the filter is in the discrete domain (see below) and the filter operates over a finite frequency range. Finally, the filter transfer function is multiplied by a constant whose value is chosen to achieve the desired level (i.e., in Equation (I-1), the magnitude of the frequency response is 1 at f = 1 Hz).

The Barnes/Jarvis/Greenhall filter is implemented in discrete time as follows (see [b-Barnes & Jarvis]). Let M equal the number of stages, and let $Y_n^{(k)}$ be the state of stage k at time step n. Then the discrete-time state equations for the filter are:

$$\begin{aligned}
Y_n^{(1)} &= \phi^{(1)} Y_{n-1}^{(1)} + P_n \\
Y_n^{(2)} &= \phi^{(2)} Y_{n-1}^{(2)} + Y_n^{(1)} - \theta^{(2)} Y_{n-1}^{(1)} \\
&\vdots \\
Y_n^{(k)} &= \phi^{(k)} Y_{n-1}^{(k)} + Y_n^{(k-1)} - \theta^{(k)} Y_{n-1}^{(k-1)} \\
&\vdots \\
Y_n^{(M)} &= \phi^{(M)} Y_{n-1}^{(M)} + Y_n^{(M-1)} - \theta^{(M)} Y_{n-1}^{(M-1)}
\end{aligned} \qquad \text{(I-3)}$$

The filter states are initialized to zero, i.e.:

$$Y_0^{(k)} = 0, \quad k = 1, 2, \ldots, M \qquad \text{(I-4)}$$

The filter coefficients are given by:

$$\begin{aligned}
&R = 2.5 \\
&\phi^{(1)} = 0.13 \\
&\omega^{(1)} = \frac{1-\phi^{(1)}}{\sqrt{\phi^{(1)}}} \\
&\text{and for } k = 1, 2, \ldots, M: \\
&\omega^{(k)} = \frac{\omega^{(1)}}{R^{k-1}} \\
&\theta^{(k)} = 1 + \frac{\omega^{(k)}\left[\omega^{(k)} - \sqrt{\left(\omega^{(k)}\right)^2 + 4}\right]}{2} \\
&\mu^{(k)} = \frac{\omega^{(k)}}{R} \\
&\phi^{(k)} = 1 + \frac{\mu^{(k)}\left[\mu^{(k)} - \sqrt{\left(\mu^{(k)}\right)^2 + 4}\right]}{2}
\end{aligned} \qquad \text{(I-5)}$$

The output of the final stage, $Y_k^{(M)}$, is the flicker noise process. The P_n are samples of a zero-mean, discrete-time white noise process. The standard deviation of this process determines the level of the flicker noise process. The quantity R determines the spacing between the successive poles and zeros. It has been found that choosing R = 2.5 and M = 8 can produce flicker noise over five decades of time; this has been verified by simulating flicker noise with these values of R and M (and $\phi^{(1)} = 0.13$), computing the TDEV statistic, and verifying that TDEV has flicker noise dependence (i.e., is approximately constant over the range of observation interval).

The above indicates that the process P_n is white, i.e., the successive samples are statistically independent. In many applications, P_n also is Gaussian; however, in the case here it is convenient to take the P_n as having a probability distribution that is uniform over the range [0,1]. It is desired that the load values also be in this range (i.e., 0% – 100%). However, choosing the P_n to be in the range [0,1] does not guarantee that the output of the Barnes/Jarvis/Greenhall filter (i.e., the $Y_n^{(M)}$) will also be in this range. But, load values that are in the range [0,1] can be obtained by scaling the $Y_n^{(M)}$ as follows. Assume that the Barnes/Jarvis/Greenhall filter has been used to generate N flicker noise samples $Y_n^{(M)}$, $n = 1, 2, 3, \ldots, N$. Let $Y_{max}^{(M)}$ and $Y_{min}^{(M)}$ be the maximum and minimum of these samples, respectively. Then the load value, $X_n^{(M)}$, corresponding to the n^{th} sample is given by:

$$X_k^M = \frac{Y_k^M - Y_{\min}^M}{Y_{\max}^M - Y_{\min}^M} = 100 \cdot \frac{Y_k^M - Y_{\min}^M}{Y_{\max}^M - Y_{\min}^M} \% \qquad \text{(I-6)}$$

Note that, for this method of scaling the output values of the Barnes/Jarvis/Greenhall filter, there will be exactly one load value of 0%, one load value of 100%, and each successive load will be different from the previous value.

Finally, the samples uniformly distributed over the range [0,1] are generated using a random number generator. The cycle length of the random number generator must be at least as long as the desired number of phase samples, to ensure that the samples exhibit the properties of an independent random process.

The flicker characteristic of a data set is seen in the TDEV calculation as zero slope. This is illustrated in Figure I.4 which calculates TDEV for a PDV pattern generated using the methodology described here and below.

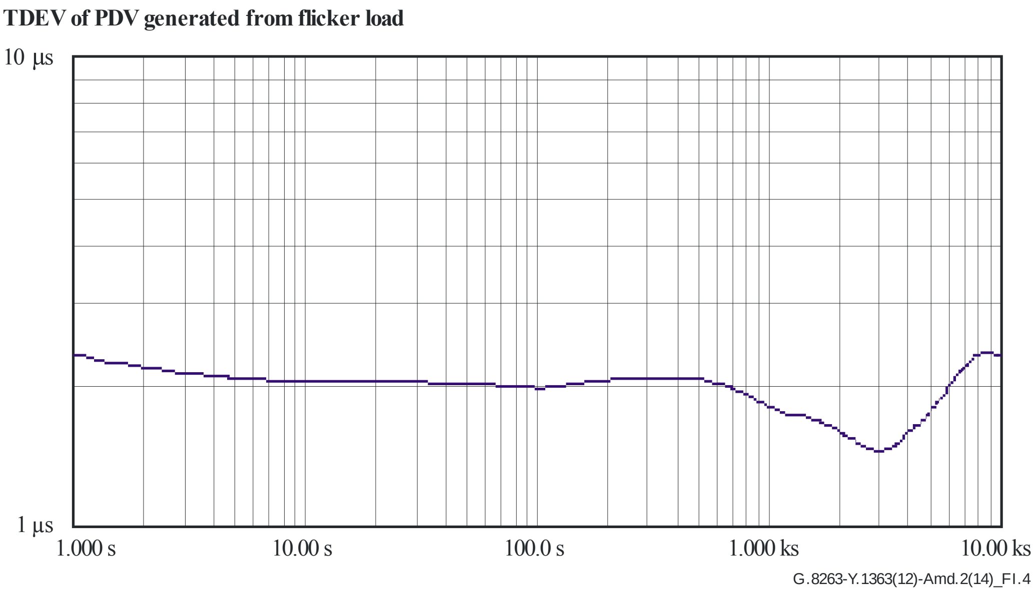


Figure I.4 – TDEV of PDV generated from flicker load

Gamma distribution generation

A gamma distribution is defined by two parameters, alpha (α) and beta (β). A third parameter, represented by rho (ρ), is needed to represent offset. This is because in its pure form, the gamma distribution has a minimum of zero, whereas minimum network packet delay for any particular scenario is a number greater than zero. The probability density function for the gamma distribution based on these parameters is as follows:

$$p_X(x) = \frac{1}{\Gamma(\alpha)} \beta^{\alpha} (x-\rho)^{\alpha-1} e^{-\beta(x-\rho)}, \qquad x \geq \rho \tag{I-7}$$

where X is the gamma random variable and x is the independent variable of the distribution.

Fitting a set of measurement data to a gamma distribution involves invoking a process of determining the three parameters, α, β and ρ. The first step, after determining ρ is to shift the data set to the classic gamma position by subtracting off ρ. In other words, ρ is assigned to zero instead. Having done this shift, there are then various methods for calculating α and β from the data. One such procedure is the *method of moments* and another is *maximum likelihood estimation*.

The *method of moments* procedure will be described here. The first step is to calculate the first and second moments m_1 and m_2 of the distribution, that is, to estimate the expected value of random variable, E(X), and the expected value of the square of the random variable, E(X^2). These moments m_1 and m_2 can be estimated using Equations (I-8) and (I-9).

$$m_1 = (X_1 + \cdots + X_n)/n \tag{I-8}$$

$$m_2 = (X_1^2 + \cdots + X_n^2)/n \tag{I-9}$$

The relationship between these moments and α and β is shown in Equations (I-10) and (I-11).

$$\alpha\beta = m_1 \tag{I-10}$$

$$\beta^2\alpha(\alpha + 1) = m_2 \tag{I-11}$$

Solving for α and β yields Equations (I-12) and (I-13).

$$\alpha = m_1^2/(m_2 - m_1^2) \tag{I-12}$$

$$\beta = (m_2 - m_1^2) / m_1 \tag{I-13}$$

To define a relationship between load and the three gamma distribution parameters, measurement data from an ITU-T G.8261.1 HRM-1 network with load incremented from 0% to 100% in 1% steps. The PDV data for each of these steps was then fitted for the alpha, beta and rho parameters.

For the modelling, the overall minimum (57.32 μs in this case) was subtracted from the data. Then α and β were calculated with a gamma distribution fit after subtracting ρ (minimum) from each segment. The approach then is to derive a closed-form solution for the three parameters α, β and ρ. For that purpose, the 100% point was kept as a special case, as a floor step occurred at 100% load (the floor moved to 95 μs above the minimum floor with the one percentile 114 μs above the minimum floor), and the points from 1% to 99% were used for curve fitting. High order polynomials (6th order) were fit to the three sets of points, the α, β and ρ sequences. Thus the equations are of the form:

$$y = Ax^6 + Bx^5 + Cx^4 + Dx^3 + Ex^2 + Fx + G \tag{I-14}$$

where x is the load value in % (i.e., x ranges from 0 to 100).

The original α, β and ρ data along with curve fits are shown in Figures I.5, I.6 and I.7.

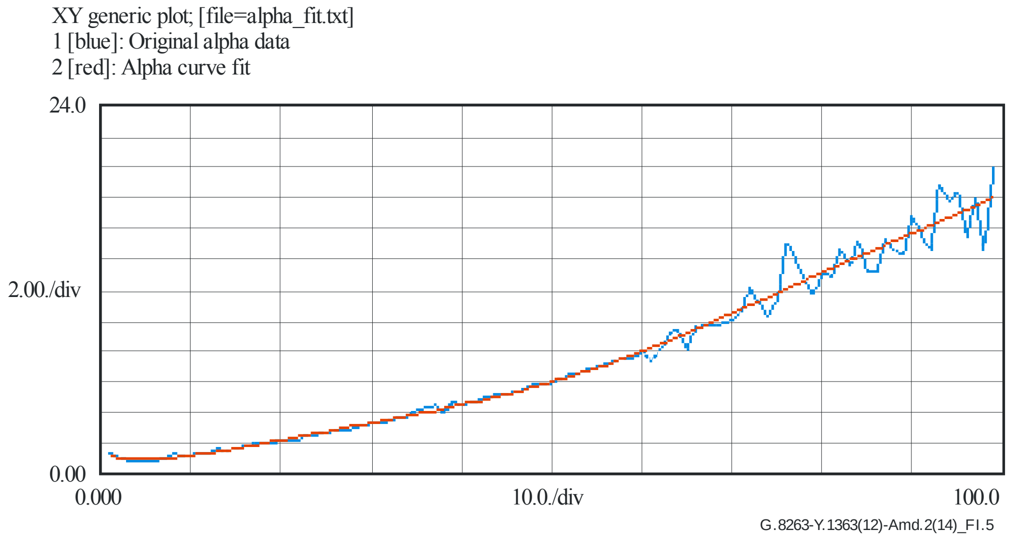


Figure I.5 – Alpha data

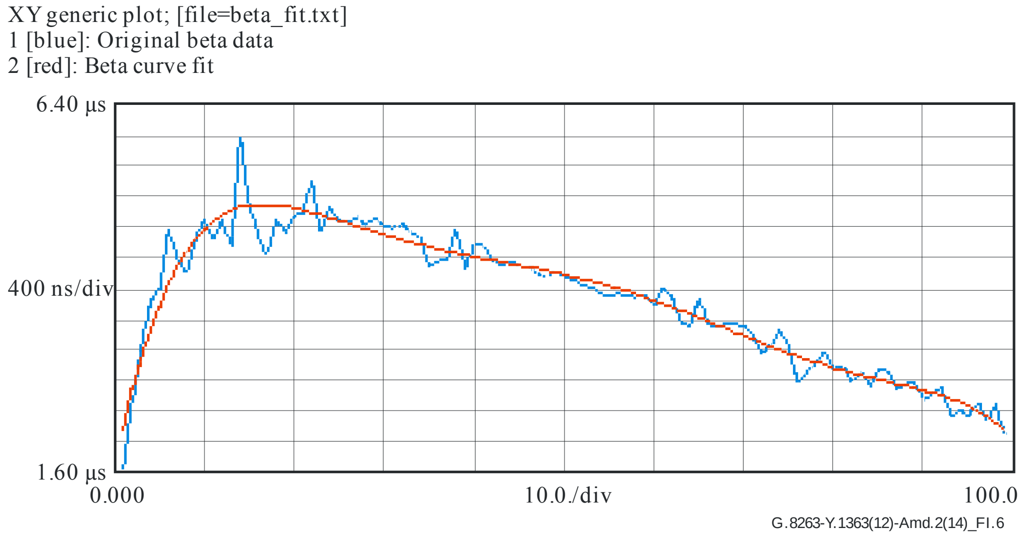


Figure I.6 – Beta data

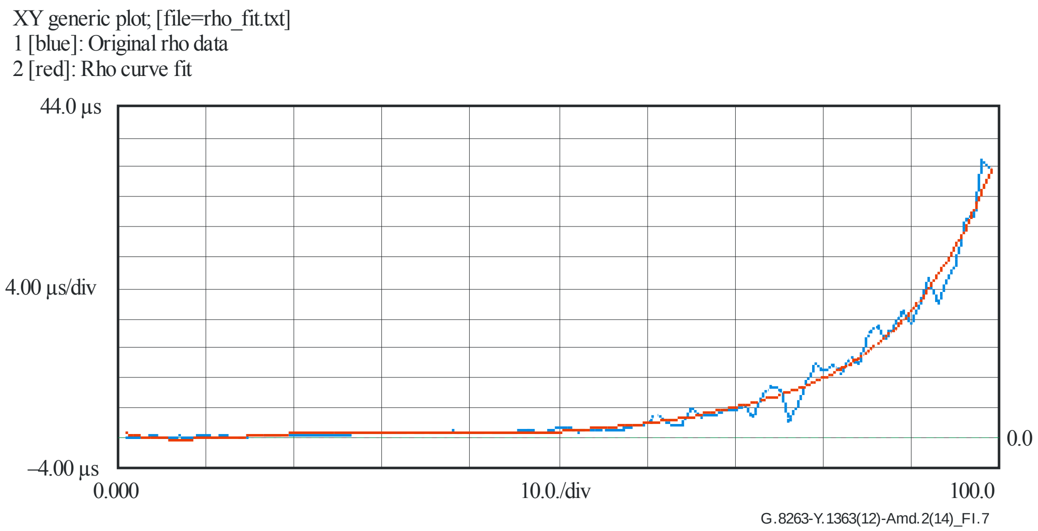


Figure I.7 – Rho data

The derived polynomial parameters are as follows (note that for higher order polynomial equation coefficients, it is important to maintain the large number of digits, as shown in Table I.2).

Table I.2 – Derived polynomial parameters

	α	β	ρ
A	3.0302171048327E-10	−3.7527709385196E-16	1.0843935243576E-15
B	−9.7822643361772E-08	1.2590219237780E-13	−2.8578719666972E-13
C	1.1854660981753E-05	−1.6595170368502E-11	2.9508400604002E-11
D	−6.6624332958641E-04	1.0886566230108E-09	−1.4410536532614E-09
E	1.8713517871851E-02	−3.7186572402355E-08	3.3119857891960E-08
F	−1.4120879264166E-01	5.9390899042069E-07	−2.9200865252098E-07
G	1.3306420437613E+00	1.6110589771449E-06	8.1781119355525E-07

To take a specific example, for load = 60%, the value 60 is applied to the equations; and

$$\alpha = 8.0255194029732\text{E+}00$$

$$\beta = 3.8429770506754\text{E-}06$$

$$\rho = 2.0554033188099\text{E-}06$$

The equations apply for load values up to 99. For load values above 99 the 100% load values are used:

$$\alpha = 2.0132036140218\text{E+}01$$

$$\beta = 2.96693980102245\text{E-}06$$

$$\rho = 5.59439990063761\text{E-}05$$

The three equations for α, β and ρ along with the special case α, β and ρ values for loads above 99% are then applied to a flicker sequence with a load ranging between 0% and 100%. The minimum PDV value of 57.32 µs originally subtracted from the data is added back in.

Flicker load gamma PDV sequence

A flicker sequence of 360 values, each corresponding to a four-minute duration, and with each value used to produce a corresponding gamma distribution using the relations described above, produces a 24 hour sequence. The resulting PDV sequence is shown in Figure I.8 along with a plot of the one-percentile taken over 200 second windows. The maximum is 146.35 µs which is 89.03 µs above the 57.32 µs floor.

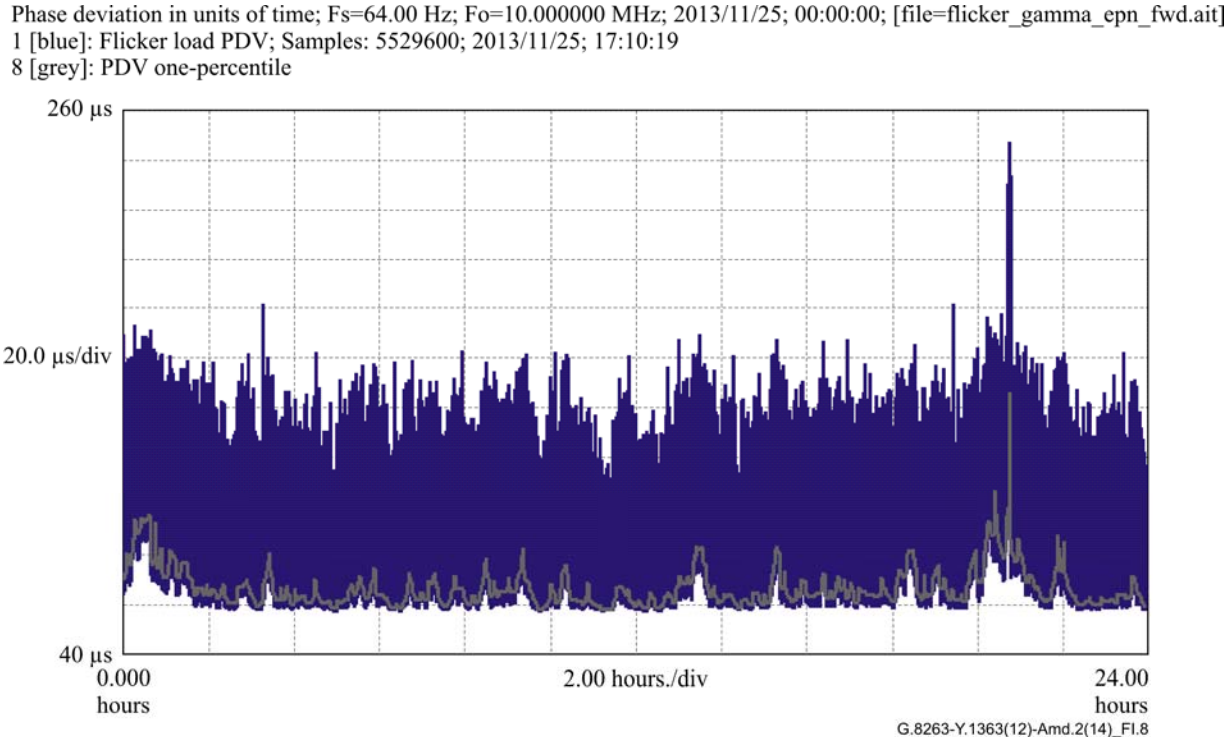


Figure I.8 – PDV one-percentile

I.2.2 PDV patterns based on combined sinusoidal waveforms

The method for generating PDV patterns described in this clause consists of a combination of sinusoidal waveforms, namely summing up sinusoidal test patterns, and normalizing the resulting pattern into the network limit specified in [ITU-T G.8261.1]. The sinusoidal test patterns are described in clause I.2.3, Steps 1 and 2 where each sinusoid is composed of a 145 µs sine function added together with a 1-ms noise pattern where the combination satisfies the 150 µs network limit.

Purpose and applicability

The single-frequency sinusoidal patterns are worst-case patterns that can be derived from the ITU-T G.8261.1 network limit. Since such patterns do not exist in real networks, another test pattern based on summing up the sine waves can be created. Even though the pattern is still artificial and does not include all PDV statistics which can be encountered, it resembles more real network behaviour. Another reason to create such patterns is that a single pattern containing multiple frequency components is faster to run through than a test sequence where the different sinusoidal patterns are run consecutively.

Parameters and example

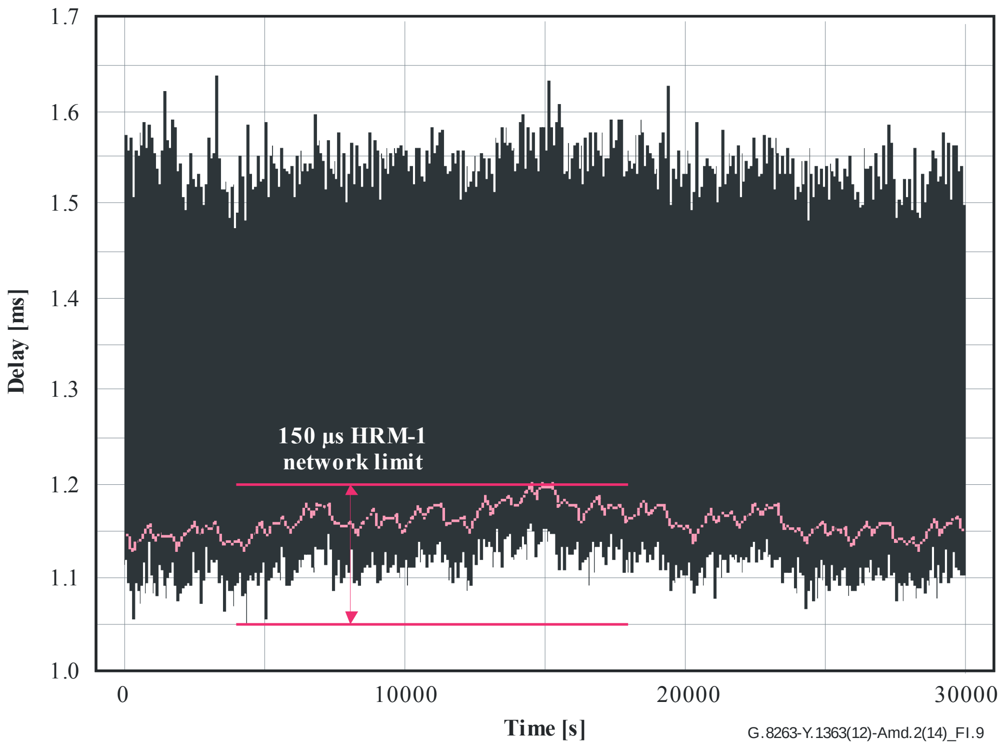
In real networks there is a distinct diurnal pattern. To mimic this pattern, the sine wave components with the longest periods are set into phases where they reach maxima at the same time. The three longest periods are 30 ks, 20 ks, and 8 ks and they are aligned to reach a peak at 15 ks. The other periods, 4 ks, 2 ks, 800 s, 400 s, 200 s, 100 s, and 50 s are slightly phase-shifted so that the same phase does not occur simultaneously in multiple components. The phases are summarized in Table I.3.

Table I.3 – Phases of the summed sine wave components

Period	30 ks	20 ks	8 ks	4 ks	2 ks	800 s	400 s	200 s	100 s	50 s
Sine phase 0° at	7.5 ks	10 ks	5 ks, 13 ks	1.5 ks	1 ks	600 s	0 s	0 s	50 s	25 s

After adding the patterns together, the values are divided by a normalizing factor so that in all 200 s windows at least 1% of packets are within the network limit specified in [ITU-T G.8261.1].

Figure I.9 below provides an example of a PDV pattern generated using a similar method.



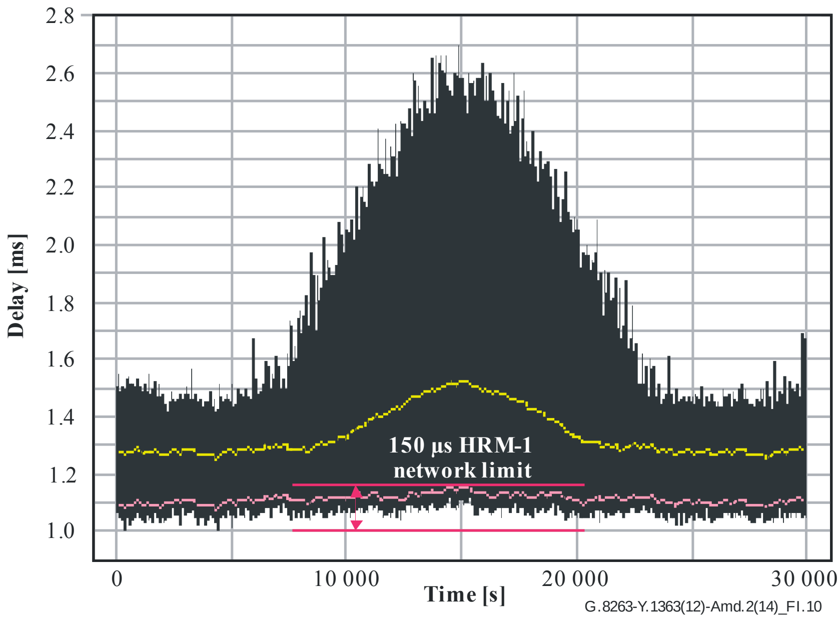
NOTE – The purple curve represents the 1% curve.

Figure I.9 – PDV pattern based on combined sinusoidal waveforms

Improving the pattern for testing packet selection capability of clocks

The sinusoidal test patterns exhibit a deficiency where clocks without packet filtering achieve the same or even slightly better performance than clocks that do packet filtering. This is because the average delay of all packets has the same or even smoother pattern than the average of the minimum delay packets.

The pattern can be enhanced by replacing a part of the values exceeding a 2% envelope by values that exhibit a pattern with a larger amplitude, as shown in Figure I.10. The fastest 2% of packets in each 200 s window may not be replaced. In this way, clocks without packet filtering will produce worse clock output than clocks with filtering. Various patterns can be used. However, the peak-to-peak amplitude of the average delay curve, calculated in 200 s windows, may be maximally 300 µs.



NOTE – The lower curve shows the 1% envelope and the upper curve shows the average delay.

Figure I.10 – Example of an enhanced PDV pattern based on combined sinusoidal waveform

I.2.3 PDV patterns based on a single sinusoidal waveform

The method for generating PDV patterns described in this clause consists of considering a single sinusoidal waveform to modulate the floor delay of random delays samples based on power-law distribution. Several frequencies can be successively applied to test properties and the tolerance of the packet slave clock. It is an adaptation to PDV noise of the traditional methods used to characterize the noise tolerance of physical layer clocks.

Purpose and applicability

This method does not intend to model typical network behaviour. However, the method may be useful in studying the detailed behaviour of packet clocks. By changing the period of the sinusoid one could obtain information about the filter bandwidth of packet clocks. On the other hand, by varying the amplitude, one could obtain information about thresholds regarding linear and nonlinear regimes of the clocks. Note however that there are no requirements defined in [ITU-T G.8263] concerning this parameter.

Parameters and example

In order to modulate the floor delay of PDV samples using a sinusoidal waveform, the process described below is suggested.

Step 1:

A sinusoidal pattern is generated, and corresponds to the low frequency component applied to the floor delay. This sinusoidal pattern, $w(t)$, is defined with 2 parameters:

– A: characterizes the peak-to-peak of the sinusoidal waveform

– T: characterizes the period of the sinusoidal waveform

The sinusoidal pattern, is given by:

$$w(t) = \frac{A}{2}\left(1 + \sin\frac{2\pi t}{T}\right) \qquad \text{(I-15)}$$

The parameters A and T are chosen from Table I.4.

Step 2:

A PDV noise is added to the initial sinusoid, based on the following probability density function:

$$p(x) = \frac{1+\gamma}{Y}\left(1 - \frac{x}{Y}\right)^{\gamma} \tag{I-16}$$

where Y is the amplitude of the noise and γ is a shape parameter. The corresponding cumulative probability distribution function is given by:

$$P(x) = \int_0^x p(u)\,du = 1 - \left(1 - \frac{x}{Y}\right)^{1+\gamma} \tag{I-17}$$

The following description describes usage in testing the tolerance of clocks to the HRM-1 network limit. However, it is not suggested to use the pattern for compliance testing because it is expected that such worst-case delay patterns never occur in practical HRM-1 networks.

To ensure that the number of samples in each window with delays less than 150 μs is close to 1% of the total number of samples in the window (i.e., that any differences from 1% are due only to statistical variability), either the amplitude Y or the shape parameter γ of the distribution of step 1 may be varied with time. If Y is varied with time, it is given by:

$$Y(t) = \frac{150\,\mu\text{s} - w(t)}{1 - (0.99)^{1/(1+\gamma)}} \tag{I-18}$$

where $w(t)$ is given by Equation (I-15) with A in μs and γ is chosen from Table I.4. If γ is varied with time, it is given by:

$$\gamma(t) = \frac{\ln(0.99)}{\ln\left(1 - \frac{150\,\mu\text{s} - w(t)}{Y}\right)} - 1 \tag{I-19}$$

where Y is chosen from Table I.4. Note that, if Equation (I-18) is used, $Y(t)$ may be outside the range in Table I.4 for some values of time, depending on the value of γ.

In addition, the quantities Y and γ may be kept fixed in time. In this case, both values are chosen from Table I.4.

NOTE 1 – If fixed Y and γ are used, they should be chosen so that the number of PDV samples in each window with delays less than 150 μs is close to 1% of the total number of samples in the window. This is especially important if step 3, which is optional, is not applied. The probability distribution given by Equations (I-15) and (I-16) may be obtained from a probability distribution that is uniform between 0 and 1 by a power-law transformation with exponent γ (i.e., $x = u^{\gamma}$), followed by a scaling by the factor Y, followed by a reflection about $x = Y/2$.

Step 3:

This step is optional; however, if it is performed, the procedure is as follows. The delay samples of the resulting PDV pattern including the sinusoidal waveform are rearranged in order to ensure that 1% of the samples are below 150 μs for each 200 s window for the HRM-1 PDV network limits. This step is applicable to jumping (i.e., non-overlapping) windows.

NOTE 2 – This step is optional because the sinusoidally-modulated PDV test pattern is not necessarily more challenging for the slave clock when FPP is smaller. For this test pattern, the portions of the test pattern that are easiest for the slave clock to tolerate are the portions at the peaks and troughs of the sinusoid, i.e., where the rate of change of the sinusoid is smallest and the floor is not changing much from one window to the next. However, the peaks are also where the FPP is smallest.

If more than 1% of the samples in a window have delays less than 150 μs, then a number of samples, N, are selected randomly from those samples whose delays are less than 150 μs. Those samples are moved to values greater than 150 μs. The new value for each sample is selected randomly from a uniform distribution that ranges from 150 µs to the maximum delay from steps 1 and 2. The number of samples N is the largest number that still leaves 1% or more of the samples with delays less than 150 µs.

If fewer than 1% of the samples in a window have delays less than 150 µs, then a number of samples, N, are selected randomly from those samples whose delays are greater than 150 µs. Those samples are moved to values less than 150 µs. The new value for each sample is selected randomly from a uniform distribution that ranges from the value of the sinusoidal modulation of the minimum delay to 150 µs. The number of samples N is the smallest number that results in 1% or more of the samples with delay less than 150 µs.

Several resulting PDV patterns including the sinusoidal waveform are generated with varying periods T, and applied successively to the PEC-S slave clock.

Table I.4 below provides a summary of the possible ranges to be considered for the parameters Y, γ, A and T when stressing a PEC-S for the HRM-1 of [ITU-T G.8261.1]. Note that if Equation (I-18) is used, A, T and γ are chosen and Y is computed; if Equation (I-19) is used, A, T and Y are chosen and γ is computed.

Table I.4 – Lower limit of maximum tolerable sinusoidal input PDV for HRM-1

Initial PDV noise parameters		**Sinusoidal waveform parameters**	
Y (µs)	γ	A (µs)	T (s)
[500, 10 000]	(−1, +4] (Note 1)	[0-150)	[200, 86 400]
NOTE 1 – γ must be strictly greater than −1. If $\gamma = -1$, the probability density function of Equation (I-16) is identically 0, and if $\gamma < -1$, the probability density function is negative. NOTE 2 – The range of A does not include the endpoint 150 µs.			

Figure I.11 below provides an example of a PDV pattern generated using this method, for the case where Y and γ are fixed in time:

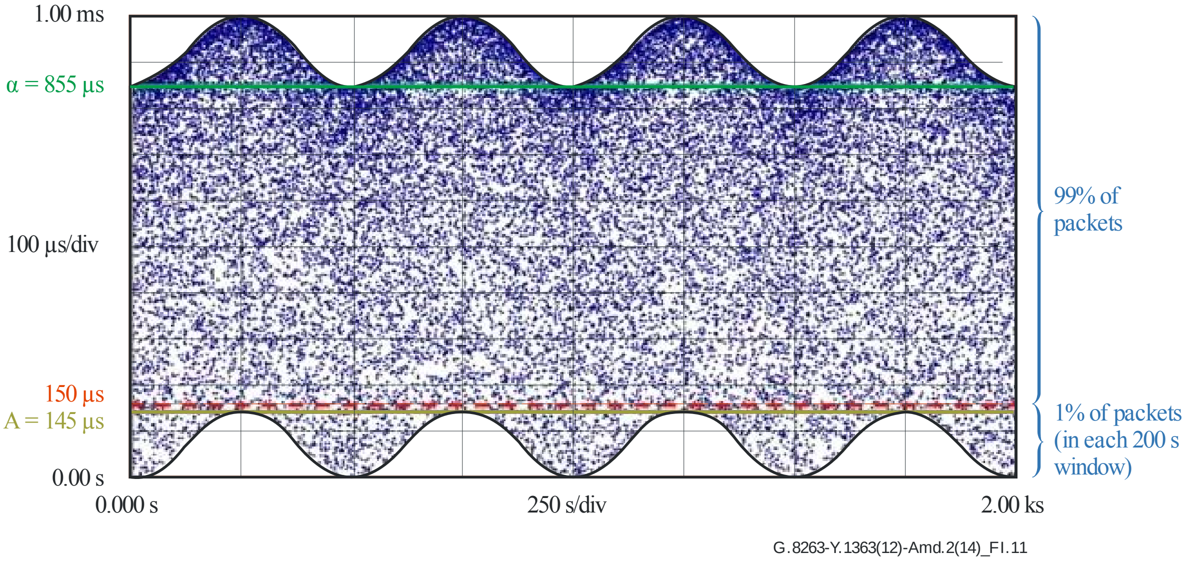


Figure I.11 – Example of a PDV pattern based on a single sinusoidal waveform (Y = 855 µs, γ = −0.5, A = 145 µs, T = 500 s)

3) Bibliography

Add the following bibliography at the end of the appendices.

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