Proposed New Subclause for 60802 Annex D in Support of 60802 SA ballot comment

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Background

- Attached (both in the following slides and as a file attachment to this pdf) is a proposed new subclause for 60802/Annex D, which describes the reason that the limits for dTE in Table 14/60802, rows 2 and 3 are asymmetric
- This was one of the items described on slide 8 of the presentation (first bullet item on that slide):

https://www.ieee802.org/1/files/public/docs2024/60802-Garner-McCall-Rodrigues-Planned-Time-Sync-Comments-SA-0524-v01.pdf

for which a planned 60802 ballot comment is needed

D.3.7 Explanation for the asymmetric normative requirements for the allowable range of dTE in Table 14, rows 2 and 3

The PTP End Instance requirements for dTE in Table 14, rows 2 and 3, are asymmetric, i.e., the allowable range in both cases is -145 ns to +20 ns. These tests are performed with the fractional frequency offset of the Working Clock (acting as the ClockSource) at the Grandmaster PTP Instance increasing at the rate of 1 ppm/s. dTE is measured at the output of the PTP End Instance clock control system after steady-state is reached, i.e., after any transients due to initiating the 1 ppm/s frequency drift rate have decayed. The clock control system is a second-order filter, with bandwidth and gain peaking requirements given in Table 11. Table 11 also indicates that the filter has a minimum roll-off of 20 dB/decade. The worst-case dTE response can be analyzed using the second-order filter model described in Annex C. The transfer function for this filter is given by Eq. (C.5). The example in C.4 shows that the damping ratio, ζ, for a filter whose gain peaking is 2.2 dB, i.e., the maximum allowed in Table 11, is 0.682 (see Eq. (C.19)). The allowable range for filter 3dB bandwidth in Table 11 is 0.9 Hz – 1.0 Hz. The example in C.4 indicates that the undamped natural frequency, ω_n corresponding to the maximum bandwidth of 1.0 Hz is 3.10 rad/s (see Eq. (C.18)).

It is well-known that if a frequency drift is applied to a linear, second-order filter with 20 dB/decade roll-off, the steady-state output has a time offset. This means that if the input to the PTP End Instance from the ClockSource (see Figure D.5) has a frequency drift of 1 ppm/s, the measured dTE output of the ClockTarget has a steady-state offset. Any errors due to other sources (e.g., timestamp granularity, dynamic timestamp error, clock noise) are in addition to this. If these other errors are symmetric about zero, the addition of the steady-state offset results in an asymmetric range of dTE.

The requirement in Table 14 is on the Working Clock (acting as ClockTarget) at the PTP End Instance minus the Working Clock (acting as ClockSource) at the Grandmaster. This difference, which is the error between the input and output and is denoted by $E(s)$ in the s-domain, is given by

$$\begin{aligned} E(s) &= Y(s) - U(s) \\ &= H(s)U(s) - U(s) \\ &= (H(s) - 1)U(s) \\ &= H_e(s)U(s) \end{aligned} , \qquad \text{(D.1)}$$

where $Y(s)$ and $U(s)$ are the Laplace transforms of the output and input, respectively, $H(s)$ is the transfer function between the input and output and is given by Eq. (C.5), and $H_e(s)$ is the transfer function between the input and error. Using Eq. (C.5), the error transfer function is given by

$$H_e(s) = -\frac{s^2}{s^2 + 2\varsigma\omega_n s + \omega_n^2}, \qquad \text{(D.2)}$$

The phase drift corresponding to an A = 1 ppm/s = 1000 ns/s^2 frequency drift is $0.5At^2$, where t is the time in seconds and the phase drift is in ns if A is in ns/s^2. The Laplace transform of this waveform is $U(s) = A/s^3$. The steady-state value of the filter output, $y_{\text{steady-state}}$, due to this drift is obtained from the final value theorem

$$y_{\text{steady-state}} = \lim_{s\to 0} sH(s)U(s) = \lim_{s\to 0} s\cdot\left(-\frac{s^2}{s^2+2\varsigma\omega_n s+\omega_n^2}\right)\cdot\frac{A}{s^3} = -\frac{A}{\omega_n^2}\,. \tag{D.3}$$

Since the 3dB bandwidth is proportional to the undamped natural frequency (see Eq. (C.23)), Eq. (D.3) indicates that the worst case, i.e., largest steady-state error occurs for the minimum 3dB bandwidth, i.e., 0.9 Hz in Table 11. In the example of Annex C.4, the undamped natural frequency of 3.10 rad/s and damping ratio 0.682 correspond to a 3dB bandwidth of 1.0 Hz. Then, due to the direct proportionality between 3dB bandwidth and undamped natural frequency (for the same damping ratio), a 3dB bandwidth of 0.9 Hz corresponds to an undamped natural frequency of

$$\omega_n = \left(\frac{0.9\text{ Hz}}{1.0\text{ Hz}}\right)(3.10\text{ rad/s}) = 2.79\text{ rad/s}\,. \tag{D.4}$$

Then, using Eq. (D.3), the steady-state error corresponding to a frequency drift of 1 ppm/s is

$$y_{\text{steady-state}} = -\frac{1000\text{ ns/s}}{(2.79\text{ rad/s})^2} = -128\text{ ns}\,. \tag{D.5}$$

Then, assuming the error without the filter is 15 ns as given in Table 14, row 1, the lower end of the range of dTE when the filter is present is

$$\text{dTE} = -128\text{ ns} - 15\text{ ns} = -143\text{ ns} \approx -145\text{ ns}\,. \tag{D.6}$$