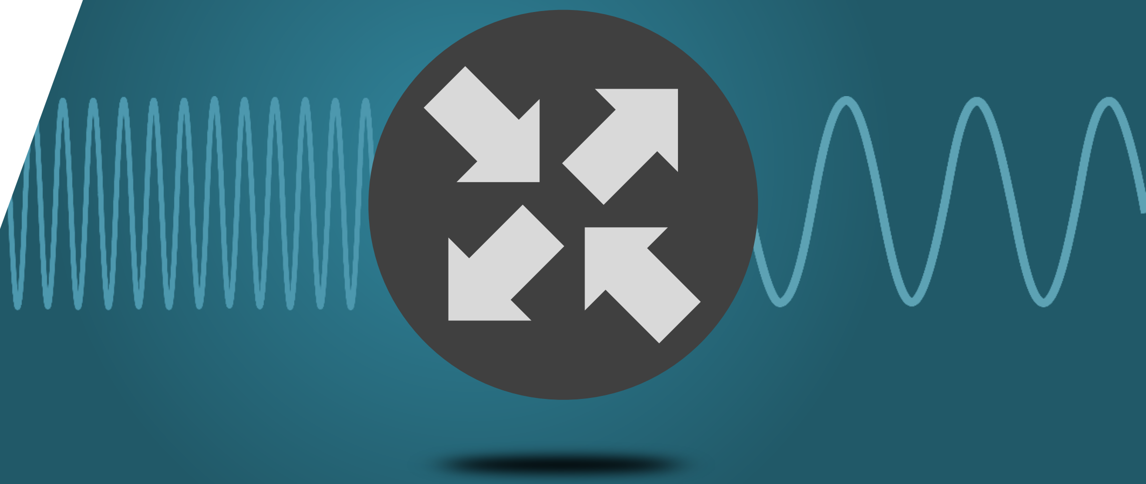
TECHNICAL OVERVIEW

The companion Technical Overview, “Testing a T-BC to ITU-T G.8273.2” describes the methods of testing a telecom boundary clock (T-BC) to meet G.8273.2. This Technical Overview describes in more detail the methods for measuring time error transfer of a T-BC, following the recommendations of G.8273.2 Appendix VI.

Measuring Time Error Transfer of G.8273.2 T-BCs



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1. Time Error Transfer

Time error transfer is a measure of how much "noise" (time error) present at the input is transferred to the output of the clock. The clock should act as a filter, removing some of the noise present at the input, therefore it is usually expressed in terms of a filter bandwidth.

There are two filter characteristics described in the G.8273.2 specification. The first is the time error transfer from PTP to PTP (and also PTP to 1pps), i.e. the boundary clock itself. PTP interfaces are generally quite noisy at frequencies close to the message rate. This is because of quantization noise in the timestamps, and also positional quantization in the physical layer components as the packets cross from the line clock domain to the internal clock domain. Therefore, G.8273.2 defines a low-pass filter function from PTP input to PTP output to remove the interface noise. The bandwidth of this filter is between 0.05 and 0.1Hz, as shown in Figure 1:

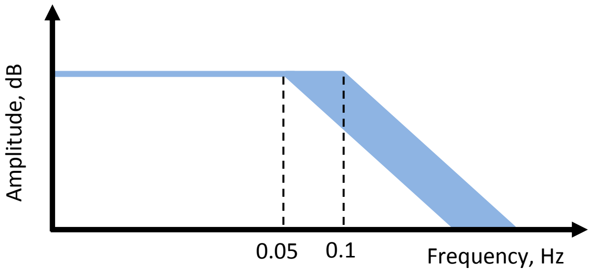

Figure 1: PTP to PTP Transfer Function

The transfer function from the SyncE input to PTP output is more complex. Firstly, there is a low-pass function in the EEC itself, defined in G.8262 to have a bandwidth of between 1 and 10Hz. The boundary clock then acts as a high-pass filter to the SyncE signal, at the same bandwidth as the PTP to PTP low pass filter. This high-pass function is a natural consequence of the way the clock works: it smooths out high frequency noise by following the local frequency reference (in this case, the SyncE), while following the PTP input at low frequencies.

The net result is that any noise (or phase wander) on the SyncE input is band-pass filtered, as shown in Figure 2:

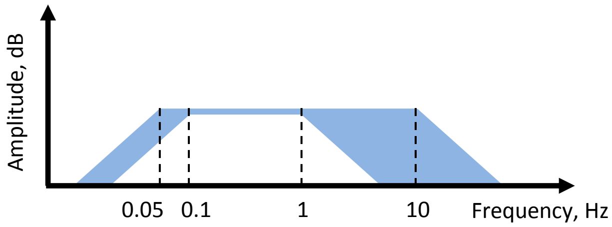

Figure 2: SyncE to PTP Transfer Function

2. What is the Transfer Function?

One of the issues with G.8273.2 (and for that matter, most ITU-T clock specifications) is that it doesn't define the transfer function except in very general terms. For example, the transfer function from PTP to PTP is defined in two short sentences (clause 7.3.1):

The bandwidth of a T-BC should not exceed 0.1 Hz and should not be less than 0.05 Hz.

In the passband, the phase gain of the T-BC should be smaller than 0.1 dB.

Note what this doesn't state:

- It doesn't define that this is a low-pass function. That may be inferred from other statements in the document, but isn't explicitly stated here
- It doesn't define the minimum phase gain in the passband (i.e. below the cut-off frequency or bandwidth)
- It doesn't define the steepness of the roll-off in the stopband

Therefore it gives broad latitude to the designer in creating a design that meets the stated requirements. It also makes it very difficult to determine whether a device meets the requirements or not. Appendix VI of G.8273.2 (Amendment 1) infers some of these missing items in order to create a testable specification. In ITU-T practice, Appendices are only informative, so it had to make some assumptions that most designers would recognise as being a reasonable interpretation of the specification:

- The PTP to PTP (and PTP to 1pps) transfer function is low-pass in nature
- The minimum gain in the passband is -3dB
- The filter characteristic should be at least as steep as a first-order low-pass filter (i.e. 20dB/decade)
- The minimum gain in the stopband is not defined, allowing for filters of any steepness above 20dB/decade

When put together, the transfer function of the filter is shown in Figure 3. In this figure, the acceptable response is the shaded region.

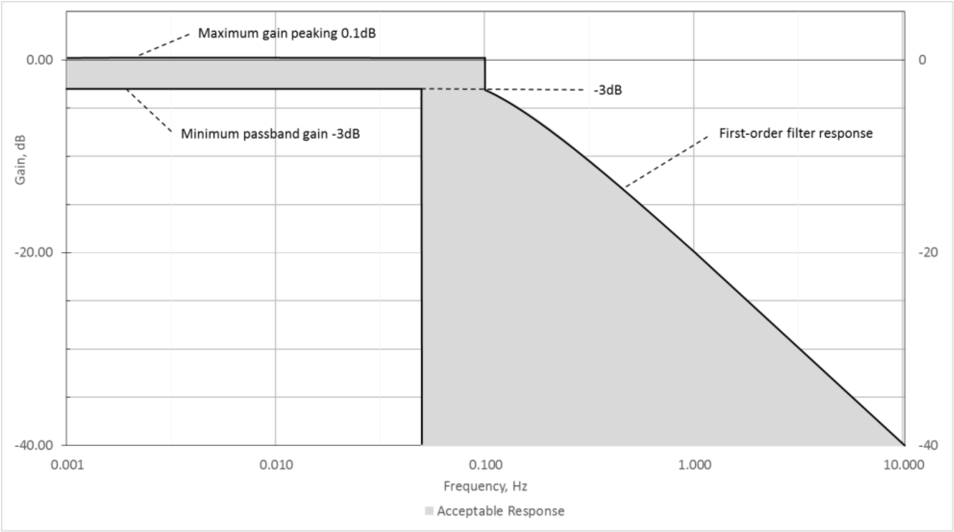

Figure 3: Frequency Response of Acceptable PTP to PTP Filter Implementation

The transfer function from SyncE to PTP is also vague, defined in clause 7.3.2 as:

The output PTP signal and 1PPS signal must correspond to the input physical layer frequency input signal on which a band-pass filter whose lower corner frequency is between 0.05 Hz and 0.1 Hz and whose upper corner frequency is between 1 Hz and 10 Hz has been applied.

In the passband, the phase gain of the EEC should be smaller than 0.2 dB (2.3%).

Applying similar assumptions gives the acceptable response shown in Figure 4.

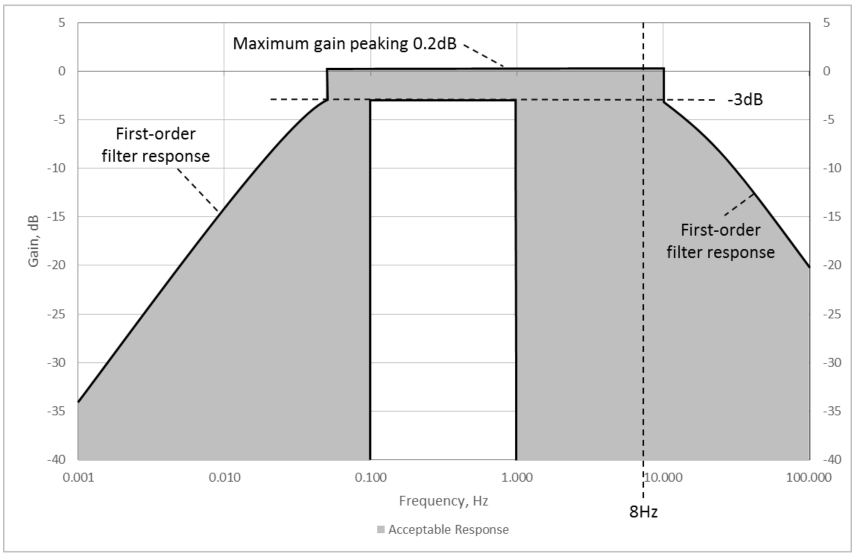

Figure 4: Frequency Response of Acceptable SyncE to PTP Filter Implementation

It should be noted that above 8Hz, the transfer function is purely theoretical. Since the PTP message rate is only 16Hz, it is not possible to input or measure tones at higher than 8Hz (the Nyquist rate of the clock).

3. Measuring Transfer Functions using Tones

Now we know that the transfer function of the T-BC should be, we can determine how to measure it. Typically, the transfer function of a clock is measured by applying sinusoidal tones at different frequencies to its input, and measuring the response at the output. The reduction in amplitude of the tones measured at the output port can be plotted on a graph, revealing the transfer function. This is shown in Figure 5:

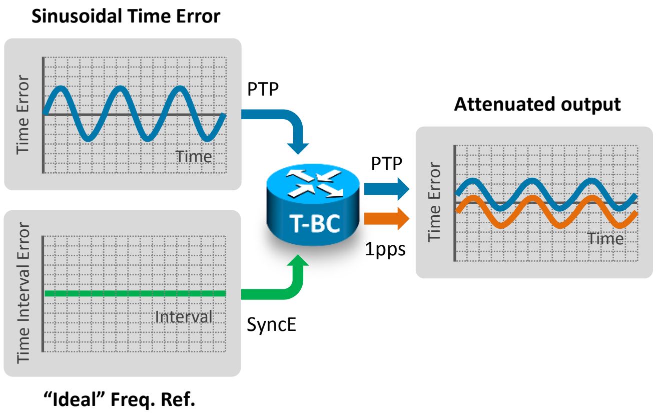

Figure 5: Measuring PTP to PTP Time Error Transfer

The tone frequencies chosen should span at least a decade either side of the -3dB bandwidth of the filter, in order to properly outline the filter response. However, the choice of tone frequency can affect the output significantly. For example, in Figure 6, the tone frequency used is 0.5Hz. The blue dots show the possible output for the 16Hz PTP messages, while the black dots are the output at the 1pps interface.

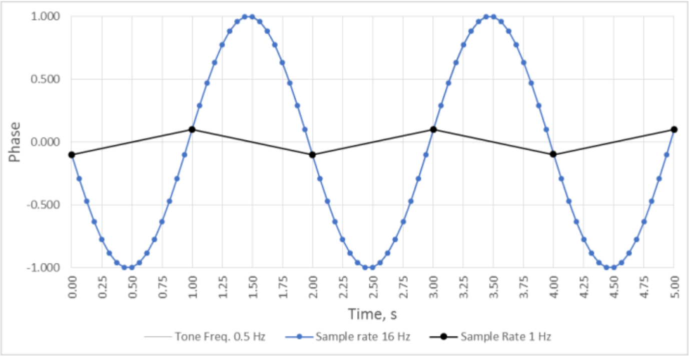

Figure 6: Using 0.5Hz as a tone frequency

For the 1pps interface, it is obvious that the signal never reaches full scale because the tone frequency is precisely aligned to the sampling frequency. In this case, the initial phase of the signal at the sampling point determines the amplitude – in some circumstances, there might be no output at all.

This also affects the amplitude of the 16Hz PTP output. It's difficult to see on this scale, but the peak output is actually in between two samples, and because the tone frequency is again in a precise integer relationship to the sampling frequency, it never reaches full scale at a sampling point.

It turns out that if the tone frequency is just slightly offset from the sampling frequency, then full scale amplitude can be achieved. For example, in Figure 7 the tone frequency is offset by 0.015Hz to 0.485Hz. While the output frequency is still 0.485Hz, it follows an envelope with an apparent frequency of 0.015Hz. In this way, the full scale amplitude is preserved provided enough cycles of the envelope are included.

(Figure 7 doesn't show the response at 16Hz sampling for clarity, but this too also exhibits full scale output with this small offset).

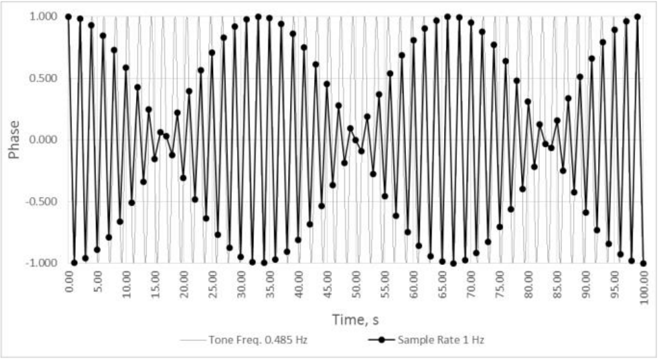

Figure 7: Using 0.485Hz as a tone frequency

The envelope patterns are related to the aliasing phenomenon, where high frequencies are transformed to much lower frequencies when sub-sampled at an appropriate rate. These patterns are called "sub-Nyquist artefacts", and exist whenever a particular frequency is sampled by a closely-related frequency.

In Appendix VI of G.8273.2, a set of frequencies have been chosen to measure the transfer function of a T-BC, both at the PTP output port and the 1pps output. They have been carefully chosen considering the sub-Nyquist artefacts that are generated to ensure that the test produces a full-scale output within a reasonable measurement time.

4. Taking into account Noise Generation

So now, we have the expected transfer function of the T-BC, and a set of tone frequencies suitable for measuring the transfer response. The tone frequencies and the expected output response are shown in Table 1. The columns contain the following information:

1. Set of test frequencies, carefully chosen to manage sub-Nyquist artefacts when sampled at 16Hz (PTP output) or 1Hz (1pps output)
2. Input waveform amplitude, chosen from the noise tolerance of the T-BC at the higher input tone frequencies
3. Expected gain range of T-BC (maximum, minimum)
4. Output waveform amplitude range, based on the input amplitude and the expected gain (rounded to the nearest 5ns)
5. Output waveform amplitude range, taking into account the noise generation of the device

Test Frequency, Hz	Peak-to-peak Input Amplitude, ns	Expected gain, dB		Peak-to-peak Output amplitude (clean), ns		Peak-to-peak Output amplitude, with ±*N* ns added noise, ns	
		Maximum	Minimum	Maximum	Minimum	Maximum	Minimum
0.00390625	200	0.1	-3	205	140	205 + *N*	140 – *N*
0.0078125	200	0.1	-3	205	140	205 + *N*	140 – *N*
0.015625	200	0.1	-3	205	140	205 + *N*	140 – *N*
0.03125	200	0.1	-3	205	140	205 + *N*	140 – *N*
0.0615625	200	0.1	n/a	205	n/a	205 + *N*	n/a
0.123125	200	-4		130		130 + *N*	
0.24625	200	-8.5		80		80 + *N*	
0.4925	200	-14		40		40 + *N*	
0.985	200	-19.9		25		25 + *N*	
1.985	200	-26		15		15 + *N*	

Table 1: Expected Output Amplitude for PTP to PTP Noise Transfer

The last column is needed, because the fourth column is the “ideal” output amplitude – it is purely the theoretical result. Real T-BCs all generate a certain amount of noise on their outputs, and this will affect the measured amplitude of the device. The amount that needs to be allowed for this noise is shown as ±*N* ns.

This noise generation is defined in clause 7.1 of G.8273.2, and can be surprisingly high. For example, clause 7.1 defines the constant time error (cTE) of a Class A T-BC to be as much as 50ns, while the maximum absolute time error can be up to 100ns. The “noise” (dynamic time error) therefore could be as much as ±50ns and still stay within the specification.

If we consider the permitted output amplitude in 1 – 2Hz region (15 – 25ns), ±50ns is clearly much larger than the expected signal. However, while ±50ns is permitted by the specification, most T-BCs don’t generate anything like that amount of noise. Another possibility then is to actually measure the noise generation, and use that as the allowance.

A third possibility is to use an estimation algorithm to remove the noise generated by the T-BC. A least squares algorithm gets very good results and is capable of estimating the amplitude to within ±10ns with a good level of confidence. Therefore N can be set to 10 in column 5 of Table 1. Calnex has an automated test script for noise transfer measurements that uses a least squares estimation with N = 10ns.

5. Measuring the SyncE to PTP Transfer Function

For the SyncE to PTP transfer function, a similar method can be used, applying sinusoidal wander to the SyncE input with an "ideal" time reference at the PTP input, as shown in Figure 8. As before, a set of tones at different frequencies can be used to plot the transfer response.

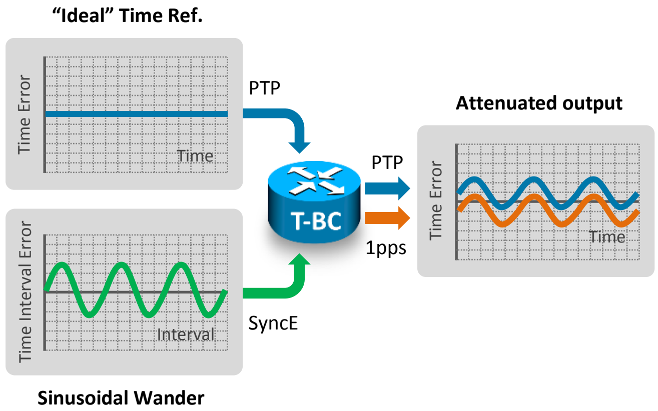

Figure 8: Measuring SyncE to PTP Time Error Transfer

The output noise of the packet interface is still an issue for accurate measurement, but as before, the least squares algorithm may be used to estimate the amplitude of the output sine wave. Therefore the same value of 5 can be used for N, the noise generation allowance in Table 2.

Test Frequency, Hz	Peak-to-peak Input Amplitude, ns	Expected gain, dB		Peak-to-peak Output amplitude (clean), ns		Peak-to-peak Output amplitude, with ±*N* ns added noise, ns	
		Maximum	Minimum	Maximum	Minimum	Maximum	Minimum
0.00390625	250	-22.3	n/a	20	n/a	20 + *N*	n/a
0.0078125	250	-16.3		40		40 + *N*	
0.015625	250	-10.6		75		75 + *N*	
0.03125	250	-5.6		135		135 + *N*	
0.0615625	250	0.2		260		260 + *N*	
0.123125	250		-3		175		175 – *N*
0.24625	250						
0.4925	250						
0.985	250						
1.985	250		n/a		n/a		n/a
3.985	250						
7.985	250						

Table 2: Expected Output Amplitude for SyncE to PTP Noise Transfer

6. Further Reading

The following documents contain the various clock specifications defined by the ITU-T:

1. ITU-T Recommendation G.8262: "Timing characteristics of a synchronous Ethernet equipment slave clock", Edition 3, January 2015
2. ITU-T Recommendation G.8273.2: "Timing characteristics of telecom boundary clocks", Edition 2, January 2017, plus Amendment 1 (August 2017)

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